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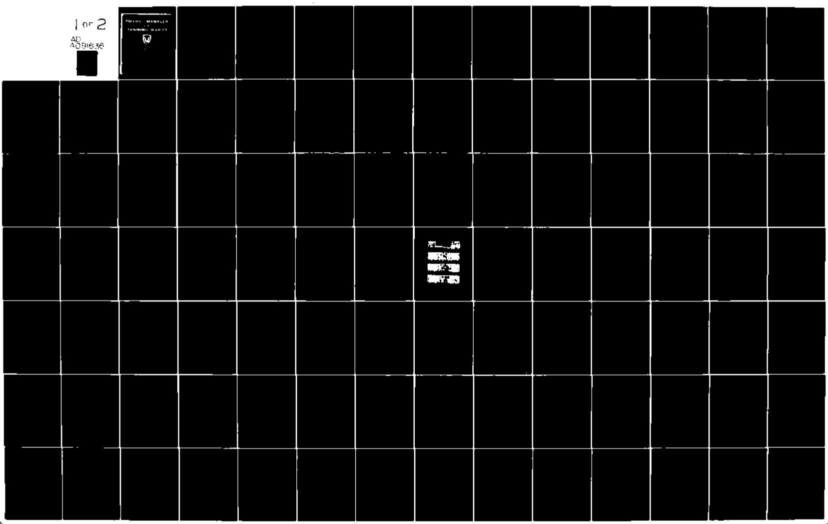

LEVEL II

CSC/TR-80/6008

PROJECT MANAGER FOR TRAINING DEVICES

PM TRADE

U.S. ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND

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COMPUTER GENERATED IMAGERY (CGI)

CURRENT TECHNOLOGY AND COST MEASURES FEASIBILITY STUDY

FINAL REPORT

SEPTEMBER 26, 1980

ORLANDO, FLORIDA 32813

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The primary purpose of this report is to determine the feasibility of developing a cost/performance, cost estimating model for CGI visual systems. In doing so, vendor surveys were made and an analysis of current and future technology/techniques was conducted. The report makes recommendations for some costing efforts to be conducted by PMTRADE, along with recommendations for other efforts.

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COMPUTER GENERATED IMAGERY (CGI) CURRENT TECHNOLOGY AND COST MEASURES FEASIBILITY STUDY

FINAL REPORT

Prepared For

U.S. ARMY PROJECT MANAGER FOR TRAINING DEVICES
Naval Training Equipment Center
Orlando, Florida 32813

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SECTION 1

SUMMARY

This report was prepared by Computer Sciences Corporation (CSC) for the U. S. Army Project Manager for Training Devices (PMTRADE) in response to NTEC Contract N61339-79-D-0008, Delivery Order Number 5. The primary purpose of this report (as outlined in the Statement of Work) is to address the feasibility of developing some form of cost/performance, cost/trade-off and/or cost estimation model for Computer Generated Imagery (CGI) visual systems. Secondary issues are current and anticipated technology and techniques. Tertiary subjects are CGI contact listings, technology constraints, CGI information sources and the identification of a CGI vanguard. The second and third subjects are those that contribute to PMTRADE's general technical knowledge of the CGI arena. The format for the report is as shown below:

- Summary
- Acknowledgements
- Introduction
- Current Technology
- Future Technology
- CGI Cost Metrics
- Conclusions
- Recommendations

Appendices to the report provide a glossary, CGI survey data elements, a CGI contact listing, system capabilities tables, CGI basic concepts information and a bibliography. In addition, a multi-volume CGI Technical Reference Library has been provided separately.

In the area of current technology, the report discusses basic CGI concepts and identifies the CGI vanguard. It discusses various vendors, especially the vanguard, their techniques and current CGI visual offerings. These product lines (offerings) are displayed in a quick-reference table for a capsule summary of basic capabilities, and for easy comparison.

Future technology is defined in terms of general visual expectations of the near-term (1-3 years), mid-term (2-7 years), and long-term (5-10 years) time frames. Information on future capabilities is derived from reviewing developmental systems (vendor and Government), current unsatisfied CGI needs, various professional conferences and publications, and offices/agencies engaged in CGI efforts. As with current technology, developmental systems are displayed in a table for easy reference.

CGI cost metrics are discussed from the aspect of CGI visual cost drivers, system trade-offs, life-cycle costing, and cost model development feasibility.

The report concludes that:

- Based on the criteria established in Section 4, there is a CGI vanguard consisting of General Electric, Evans and Sutherland/Redifon, Singer-Link, and McDonnell Douglas. These vendors represent those who can currently respond to PMTRADE's real-time visual system requirements. This vanguard, however, will begin changing over the near- to mid-term (with additions versus deletions).

- Current technology is impressive and current product lines offer multi-capable systems with a wide range of options for tailoring these products to specific needs.

- Future technology will, most likely, be incremental in the near-term with quantum leaps occurring in the mid- to long-term. The near-term improvements will be in edge capacities, data base generation techniques, storage techniques, texture, FOV, area of interest displays, and, possibly, utilization of VLSI technology. The strides forward in techniques and capacities will be forced by user pressures, stated needs, and by competition.

- Numerous sources of current and future technology information are available to PMTRADE. Among these are vendors, Government agencies, Government reports and studies, professional conferences and publications. Notable among these are:

  ACM "SIGGRAPH" Conferences
  AIAA "Simulation Technology" Conferences
  "Interservice/Industry Training Equipment" Conferences
  NASA Ames/Army Aeromechanical Labs.
  NTEC (N214, N732, N74)
  SPIE "Simulators and Simulation" Conference
  Vendors

- The development of a usable, easily maintainable, and cost-effective costing model for CGI is,

by all indications, not feasible at this time. Inhibiting factors are differences in data base techniques, languages, image generation techniques, the implementation of special features (texture, tiling, etc.), hardware architectures, and system constraints. Factors vary from vendor to vendor, and within vendor product lines.

- Cost drivers and trade-off factors can be considered during the development of system concepts and requirements. These factors could be determined with vendor cooperation and displayed in matrix form.

Readers must keep in mind that this report represents a "snapshot in time" with respect to the technical content and system capability descriptions. While no quantum leaps forward are in the near-term picture, incremental advances are made continuously. For this reason, contact should be maintained with the suggested sources of CGI technology information discussed in Section 5 and Appendix C.

SECTION 2

ACKNOWLEDGMENTS

A report of the nature and scope of this CGI report cannot be accomplished in a void or singularly. It requires, and CSC has received, the indepth cooperation and assistance of many diverse individuals and organizations.

While not all those queried provided the cooperation desired, enough Government, academic and industry organizations did respond to allow for the completion of this final report. CSC's ability to respond to the needs of PMTRADE, as stated in the Statement of Work, regardless of the subjects depth, is due to the assistance of those who did provide input data. The following organizations must be recognized for their part in contributing data, assistance or support to this effort:

- American Airlines (Ft. Worth, TX)
- Boeing Corporation (Seattle, WA and Witchita, KS)
- Defense Mapping Agency (Washington, DC)
- Evans and Sutherland Corporation (Salt Lake City, UT)
- General Electric Company (Daytona Beach, FL)
- Gould, Inc. (Melville, NY)
- Grumman Aerospace Corporation (Bethpage, NY)
- Logicon, Inc. (San Diego, CA)
- McDonnell Douglas Electronics Company (St. Charles, MO)
- NASA-Ames Research Center (Moffett Field, CA)
- NASA-Johnson Space Center (Houston, TX)
- Naval Training Equipment Center, Experimental Computer Simulation Laboratory, N-74 (Orlando, FL)

Naval Training Equipment Center, Engineering Concepts, N214 (Orlando, FL)

Naval Training Equipment Center, Visual Technology Research Simulator (VTRS), N-732 (Orlando, FL)

Ohio State University (Columbus, OH)

Redifon Simulation, Inc. (Arlington, TX)

Mr. John Sinacori, Private Consultant (Hollister, CA)

Singer-Link Division (Sunnyvale, CA)

University of Central Florida (Orlando, FL)

University of Southern California, Information Sciences Institute, Dr. D. Cohen (Marina Del Rey, CA)

U.S. Air Force Flight Dynamics Laboratory (Wright-Patterson AFB, OH)

U.S. Air Force Tactical Air Warfare Center (Eglin AFB, FL)

U.S. Army Aeromechanical Laboratory (Moffett Field, CA)

Special appreciation must go to Mr. Mike Cyrus and Dr. R. Barker (Boeing), Dr. C. Lindahl, Mr. J. Booker, Mr. J. Jancaitis and Mr. G. Palmer (NTEC), Mr. J. Sinacori (private consultant), Mr. Robert Gullen (Logicon), Mr. J. Eicher (FDL), and Col. A. Deel (ARC).

SECTION 3

INTRODUCTION

CGI visual systems have played an important role in conventional flight training for almost two decades. These CGI systems, when installed in a total simulator, have allowed for effective, acceptable transfer of training, cost savings and safety in the total pilot training field. The fact that the Federal Aviation Administration has approved the CGI based simulators of several aircraft for total transition training, without flight time in the actual airplane, is vivid evidence of the acceptability of CGI techniques.[1]

Effectiveness studies on flight simulators since 1939 have repetitively shown that simulators save flight time.[2] Any savings in actual flight time translates into dollar savings in terms of fuel savings, decreased maintenance, lower parts usage and extended aircraft life. Positive results are shown even after amortizing the cost of the simulators against the above dollar savings. The following statements support this claim.

"A Navy study concludes that the new P-3C flight simulator, when used for transition training of about 200 Naval pilots a year, saves enough flight time to be amortized in about two years. A Coast Guard study concludes that its new simulator, used for transition and proficiency training of about 500 pilots per year for the HH-52A and HH-3F helicopters, can be amortized in about two years."[3] In addition, the

[1] NTEC Technical Report, "Summary of the CIG Survey", (Draft), February 1980, p. 8.

[2] Ibid., p. 20.

[3] Ibid., p. 21.

results of a Cost and Training Effectiveness Analysis (CTEA) by the Army suggests that "use of the new CH-47 simulator for transition training should save about $8,000 per pilot".[4]

The safety afforded by these simulators cannot be assigned a dollar value. CGI based simulators can be invaluable in terms of safety, especially when training in volatile situations such as nap-of-the-earth (NOE) flight.

The above discussions provide the basic reasoning behind the increased use of CGI based trainers by DOD. It is expected that the trend towards CGI systems will continue for DOD in general, and for the Army in particular. There will be increased requirements for sophisticated, complex CGI based trainers to meet Army needs, especially in the rotor craft NOE and ground simulation (tank driver, tank fire, etc.) environments. As the Army's Manager responsible for the design, development and procurement of system and non-system related simulators, PMTRADE must maintain a data base of knowledge concerning current and potential CGI capabilities and techniques.

The primary purpose of this report is to address the feasibility of developing a cost/performance, cost trade-off and/or cost estimating model applicable to CGI. Secondary and tertiary items, as contained in the Statement of Work, are also covered in such a manner as to contribute to the PMTRADE CGI knowledge data base. It must be noted here, early in the report, that this effort represents a "snapshot in time" with respect to CGI technology. This is a dynamic field

[4] Ibid., p. 21.

producing continuous incremental advances and periodic quantum leaps in techniques and/or capabilities. Only through continuous research efforts, and an intimate knowledge of the CGI vendors and various research efforts, can more than a cursory knowledge of CGI technology be maintained.

Compilation of this report involved research, planning, a determination of the data required, the design of survey forms, the contacting of organizations to be queried via telephone, a mail survey of targeted agencies, a telephonic follow-up campaign to help ensure responses, the compilation and analysis of collected data, and the preparation of this report. These efforts were supplemented by visits to selected organizations, and extensive document research.

Appendices A, B and C are directly related to, and are a result of, the methodology used in compiling this report and are, therefore, discussed here. Appendix A is a Glossary of CGI related abbreviations, acronyms and terms encountered during the compilation of data for this report and is included as a necessary means of increasing CGI technical knowledge. Attachment 1 to Appendix A specifically addresses cost related terms. Appendix B is an example of the attachment and data elements list originated during the planning phase of this study. The attachment was included in letters to organizations, agencies and/or individuals selected for surveying. Its purpose was to outline the principal efforts related to the study, identify the data elements about which technical information was desired, and provide a format for displaying the requested information. A similar effort was directed at Governmental developers, procurers and/or users

of CGI visual systems in an attempt to document ongoing efforts that may be of interest to PMTRADE. Appendix C is a contact listing of CGI expertise. This appendix lists, in alphabetical order, organizations or Government agencies, mailing addresses, the names of individual contacts and their telephone numbers, and identifies the areas of CGI visual technology in which the listed organization or individual can most assist. Due to the importance of maintaining a base of knowledge on current and anticipated CGI technology/techniques, the appendix is probably the most valuable section of the final report.

Complementary and/or parallel efforts by NTEC (N-74)/University of Southern California Information Sciences Institute, the U.S. Air Force Flight Dynamics Laboratory/Logicon, and the U.S. Army Aeromechanical Laboratory/Boeing and Mr. Sinacori provided additional indepth data in support of this report. The U.S. Air Force Tactical Air Warfare Center "Simulator Comparative Evaluation" Report also provided data.

This report is organized into eight (8) sections and six (6) appendices. Section 1 is a summary of the final report. Section 2 acknowledges the contributions made by the many individuals and organizations who provided data or otherwise supported the effort to produce this report. Section 3 is an introduction and discusses the purpose of the report, the path followed in preparing it, and the report content by section and appendix. Section 4 along with Appendices D and E accomplishes the following:

- Provides a brief CGI familiarization discussion

- Identifies the vanguard of CGI technology
- Discusses current capabilities
- Provides a "quick reference" system capabilities table
- Discusses various CGI techniques
- Discusses technology constraints

Section 5 provides a synopsis of anticipated capabilities and is a supposition based on interpretation of discussions contained in the various complementary efforts discussed above and input from the various contributors to this report. This section also discusses those activities, documents or organizations which should be consulted in order to maintain data on current and anticipated CGI capabilities and techniques. Section 6 addresses the cost model feasibility question posed by PMTRADE. This is accomplished by discussing life-cycle and trade-off costing techniques and models, CGI system and subsystem trade-off topics, CGI system cost data requirements and use, and the feasibility of combining the above into an easily usable and maintainable model. Section 7 provides conclusions to the discussions undertaken in Sections 4, 5, and 6, while Section 8 offers recommendations concerning the results of the total study effort.

Appendices A, B and C were discussed previously. Appendix D is a brief discussion of basic CGI concepts. Appendix E provides, in table form, a quick-reference index to the current capabilities of those systems surveyed during this study. Finally, Appendix F is a bibliography of books, papers, articles and documents related to all aspects of CGI visual system technology.

A multi-volume CGI Technical Reference Library is provided, under separate cover, to complement this report and make it more useful to PMTRADE. The library is divided into three categories as shown below:

- Vendor company (corporate) and product line information
- Government documents, studies and reports
- Technical reference literature in the form of published papers, articles, etc.

The answers received in response to the survey conducted for this report are included in this library.

SECTION 4

CURRENT TECHNOLOGY

This section addresses the broad scope of current CGI technology. Basic concepts, current vanguard of CGI technology, current systems capabilities and techniques and constraints are discussed.

Basic CGI Concepts

Appendix D is an extract from Gullen's efforts in support of the U.S. Air Force Flight Dynamics Laboratory.[1] This extract provides an excellent introduction to the basic concepts of CGI and should be referred to by the neophyte reader.

The CGI Vanguard

Identifying a vanguard of technology in almost any field requires the determination of a basis for the selection of a vanguard. For the purposes of this study, the vanguard is deemed to be those vendors with a capability of meeting current PMTRADE needs for real time and CGI visual systems, as demonstrated by having delivered such systems for use in a military simulator. Based on this criteria, the current CGI vanguard is deemed to be:

- General Electric Company
- Evans and Sutherland/Redifon
- McDonnell Douglas Electronics Company
- Singer Company - Link Division

[1] U.S. Air Force Flight Dynamics Laboratory "CIG Applications Study", March 1980, pp. 40-51.

Current Technology

This section contains a brief discussion of each vanguard vendor and their current offerings. There may be a question regarding the exclusion of Gould as a member of the CGI vanguard. They do have a currently operational CGI system which is described in Table E-1. CSC, however, did not resolve that any GVS-1 systems had been delivered in operational military trainers as yet. The vanguard is subject to expansive change, as discussed in Section 5.

Each of the systems discussed are summarized in Table E-1 (Appendix E) for easy reference. Much of the information concerning vendors and the general descriptions of their techniques was condensed or extracted from an article in Computer Graphics World, May 1980, entitled "A History of Visual Flight Simulation". This article was coauthored by Bruce Schachter and Narendra Ahuja and was found to be a most comprehensive article on vendors and current technology. A discussion with Mr. Schachter has revealed that the authors are updating this article and upon release, it should be included on the current reading list for all involved in CGI visual systems and simulators.

General Electric Company:

Although GE is not the oldest company involved in flight simulators, it was the first company to produce a simulator utilizing CGI technology (1958). GE provided the Navy with a full color Advanced Developmental Model (ADM) simulator in 1972, the Air Force with the Advanced Simulator for Undergraduate Pilot Training (ASUPT) in 1974, Boeing with the first full color day/night CGI visual simulator in 1975,

and, in 1978, delivered AWAVS (Aviation Wide Angle Visual System) to NTEC. GE's current offerings are the COMPU-SCENE I and II systems which are described in Table E-1.

> G.E.'s current real time systems process three cycles concurrently. These computation cycles are slaved to an update rate of 30 images per second. The three cycles are connected serially. They will be referred to as Frame I, Frame II, and Frame III operations.
>
> The Frame I hardware consists of a 32 bit computer, an array processor, and peripherals. The Frame I software mainly performs data management, monitoring, and control tasks. It retrieves from disk the data describing each new geographic region the pilot encounters.
>
> The Frame II hardware consists of a Controller, Priority Processor, a bank of non-dedicated Programmable Pipeline Processors, and an active environment core storage unit. The Frame II Controller uses a distributed approach to control authority. Each distributed control processor is a fixed program sequencer designed to support a particular function with a minimum of external interaction. Some of the functions controlled are environmental update; data processing; bus interface; active face, block, cluster, and region assignment; and vector processing. The operation of each sequencer is basically asynchronous, with data and control transfers between sequencers handled by a first in first out memory structure. This allows each sequencer to run at the maximum possible rate while minimizing critical timing interrelationships. Frame II receives blocks of environmental data from Frame I and places them in core. Generic three-dimensional models also reside on-line in core. The active environment memory contains all the information required to construct a scene. A new two-dimensional image is computed from this data for each display channel, each raster period. These images are true perspective views changing every 1/30 sec with the pilot's position and aircraft orientation.

Frame II sends Frame III edge, face, point feature, texture, and priority (i.e., hidden surface) data each frame time. Frame III uses this information to construct a recognizable image in raster format. Frame III thus must organize this data so that each scanned pixel can be rapidly computed from the right scene primitives. A number of hardware modules are responsible for this function. For each active raster line, an Edge Generator determines which edges intersect the line, calculates the points of edge intersection with the top and bottom of the raster line, and outputs these intercept values to the Edge Orderer along with the edge number. The Edge Orderer orders edges along a raster line first by channel, and within a channel by element number. The Edge Orderer also obtains stored values associated with each edge and sends them to a Priority Resolver. The Priority Resolver arbitrates priority conflicts, calculates edge smoothing area weighting functions, and outputs visible edge data to the Video Processors. A Video Processor also receives point feature and texture data from Point Source and Texture Generators. For each display channel, a Video Processor computes and outputs analog color video in noncomposite forms. As many as ten displays may be abutted to provide the pilot with up to a 360° FOV.[2]

Figures 4-1, 4-2 and 4-3 are block diagrams of General Electric's CGI visual systems. These block diagrams are redrawn from diagrams which appeared in reference 2 below, with permission of the General Electric Company.

The data bases for these flight simulators are created off-line, with U.S. Defense Mapping Agency data as the primary source of information. The Defense Mapping Agency supplies data in the form of terrain and culture files. A terrain file is an array of elevation values for a region of the Earth. A culture file holds encoded descriptions of the man-made and ecological surface features residing within a given terrain

[2] Schachter, B. and N. Ahuja, "A History of Visual Flight Simulation", Computer Graphics World, Volume 3, #3, May/June 1980, pp. 21-25.

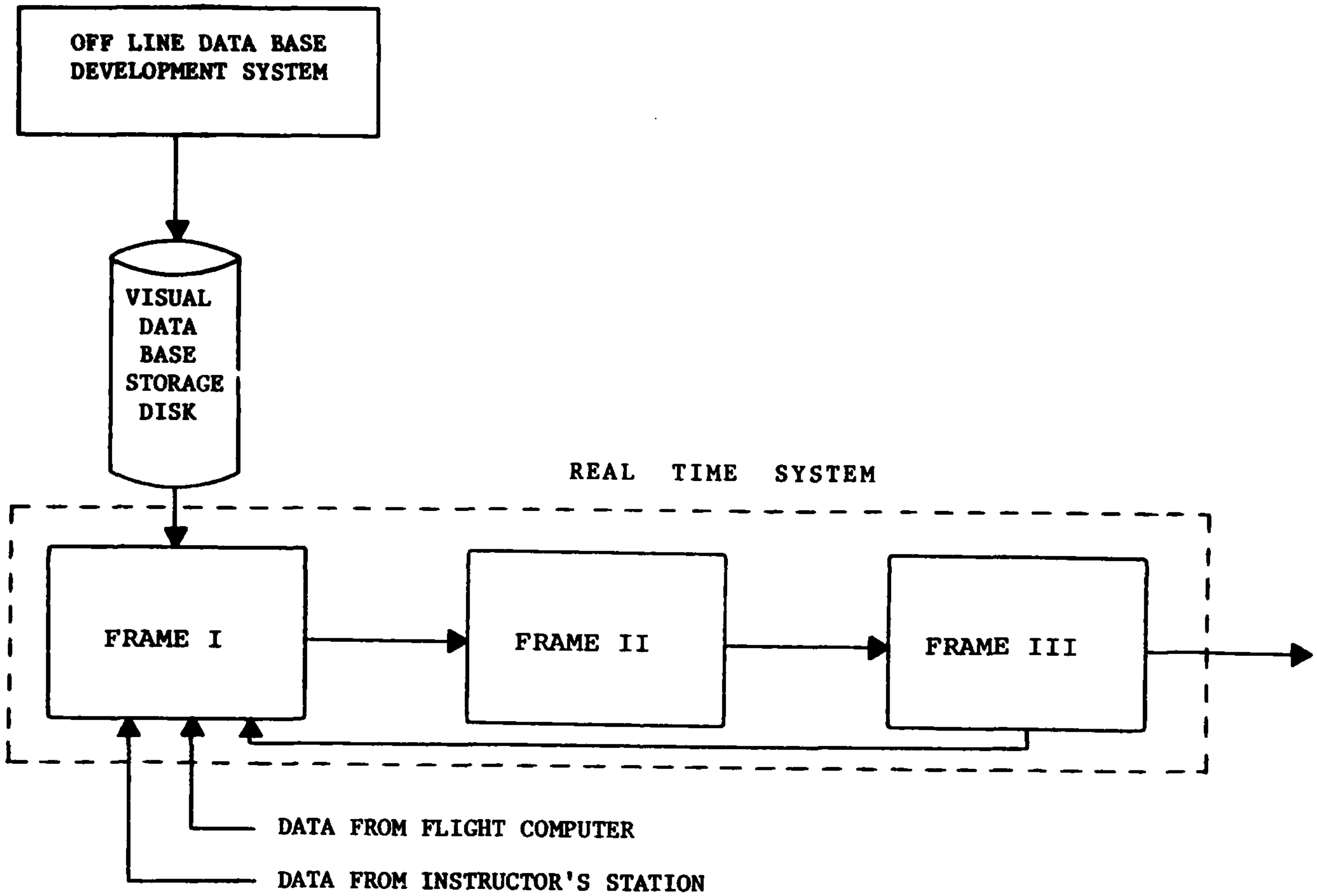

FIGURE 4-1. MACRO BLOCK DIAGRAM OF THE GE CGI SYSTEM

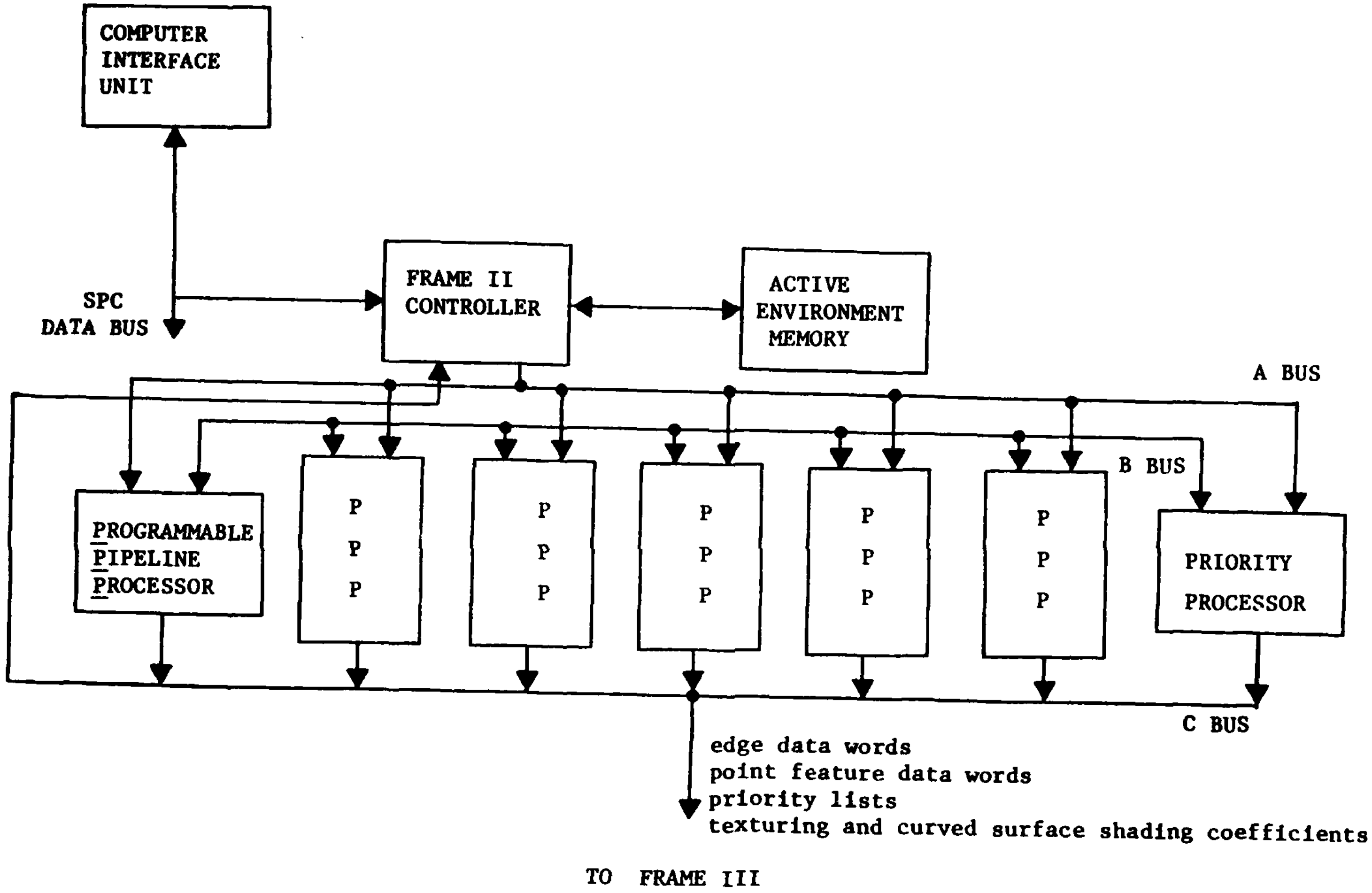

FIGURE 4-2. DETAILED BLOCK DIAGRAM OF GE CGI VISUAL SYSTEM, FRAME II

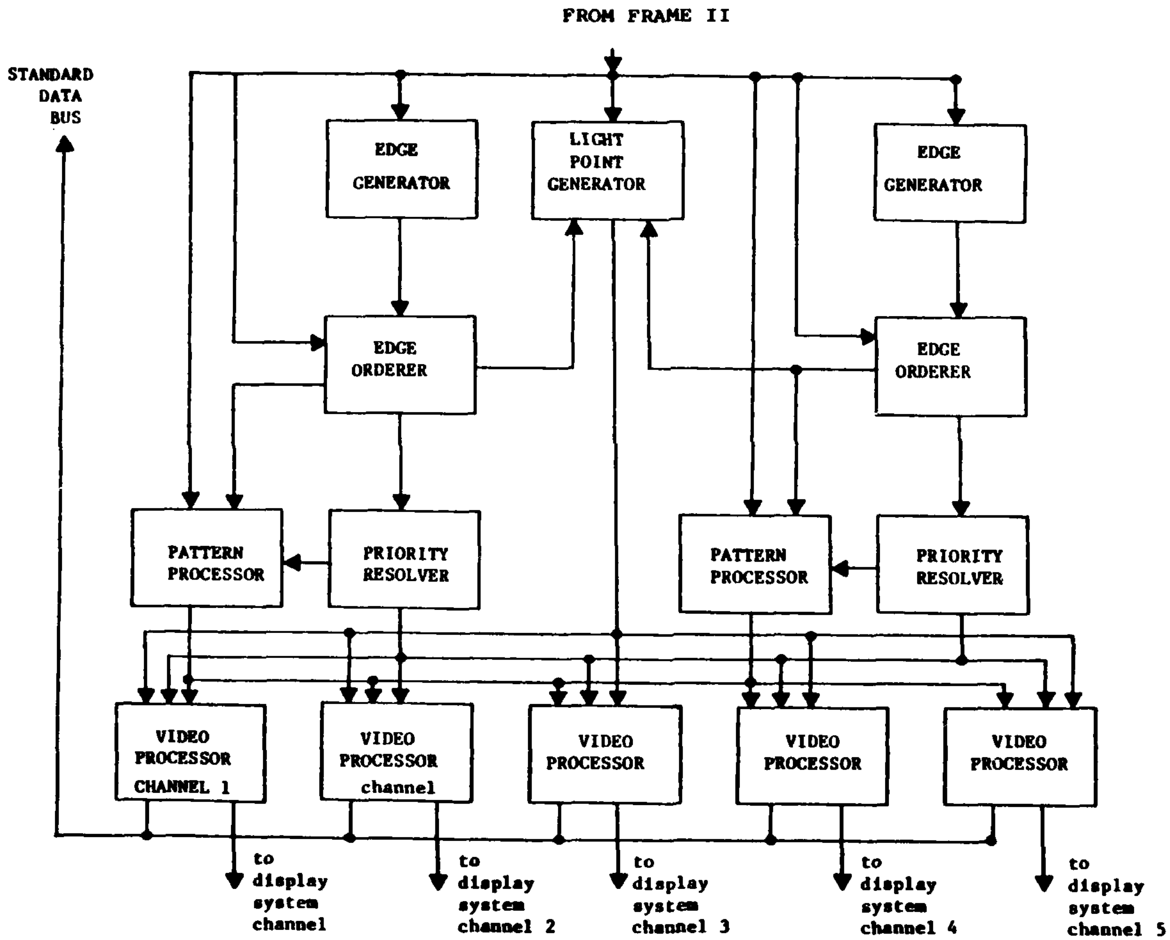

FIGURE 4-3. DETAILED BLOCK DIAGRAM OF GE CGI VISUAL SYSTEM, FRAME III

> region. Most feature types are represented by a polygonal boundary and descriptor table. The table includes such information as surface type (e.g., forest), predominant makeup (e.g., coniferous trees), and average height. The locations of some other features such as bridges, dams, walls, and pipelines are specified by polygonal lines; while others such as tall buildings and water towers are given as points. G.E. augments the DMA data with information from maps, photographs, and airport blueprints.
>
> G.E.'s off-line data base development software fits a hierarchy of triangular faceted surfaces to the Defense Mapping Agency terrain data. Each of these approximation surfaces corresponds to a different level of detail to which the terrain is modelled. The culture polygons are placed on top of (i.e., intersected with) the triangular terrain surfaces. This automatically generated data base covers most of the geographic area modelled. However, the data bases for airports and other special areas of interest are created manually with an interactive computer graphic system. The manually and automatically generated data bases are merged and placed onto a visual data base disk.[3]

GE provides many special features such as curved surface shading, texture, multiple moving objects, environmental effects (weather), and special effects (smoke, etc.). These features allow for the tailoring of systems to meet specific needs.

Evans and Sutherland/Redifon:

Evans and Sutherland Company (E&S) and Redifon Simulation, Ltd., must be discussed as one because, in a sense they are one. While E&S does market a line of interactive graphics systems, their CGI visual systems are generally sold to Redifon for integration into total simulators. E&S/Redifon

[3] *Ibid.*, pp. 20-21.

current offerings consist of the NOVOVIEW line with the Special Performance 1 and 2 systems, and the Continuous Tone systems, number 5 (CT-5).[4] The NOVOVIEW line represents a low cost, real time CGI visual capability. NOVOVIEW was introduced in 1973 as a night only system. Improvements in capability were provided in 1974, 1975 and 1976.

> NOVOVIEW SP1 was introduced in 1977. It provides increased surface capacity (200 surfaces), solid and moving objects, directional lights, and a dusk mode capability. The latest NOVOVIEW SP2 system has a newly developed high quality color display. A shadow mask CRT is used with linear amplifiers for beam deflection. Lights are simulated by directing the electron beam to the proper point on the CRT, and turning it on with the correct color. A linear deflection system is used to paint a full 800 line raster, with all surfaces displayed in a raster scan mode. The raster is rotated in real time to be parallel to the horizon. The refresh rate is 40 frames per second for the daylight mode and 30 for the night mode. Image brightness is carefully controlled to eliminate flicker. Day, dusk, and night scenes of moderate complexity (450 surfaces) are produced. Three-dimensional objects are displayed at varying levels of detail. System overload conditions are handled by reducing the refresh rate. If the refresh rate reaches some lower bound, fewer scan lines are computed, with the surviving scan lines spread out. This allows for increased processing time per scan line.[5]

Figure 4-4 is a block diagram of a special performance system.[6]

---

[4] During the final states of the preparation of this report, it was learned from E&S that the CT-4 system was no longer being offered, however, the Schachter and Ahuja discussion of CT-4 is included here for information.

[5] Schachter and Ahuja, p. 27.

[6] Extracted from "NOVOVIEW SP2 Color Day/Dusk/Night Computer Generated Visual System", Redifon Simulation, Inc. Product literature prepared for NTEC, April 1980.

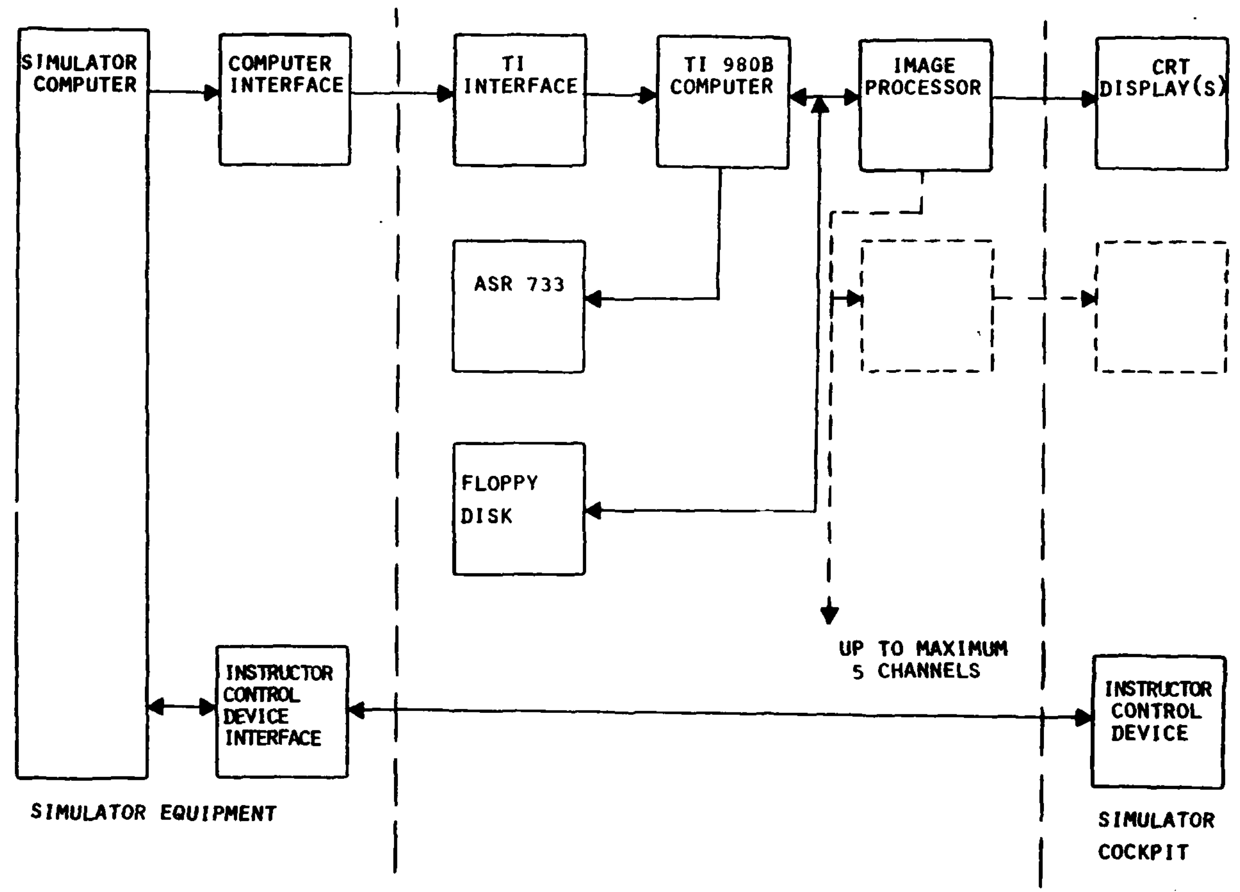

FIGURE 4-4. NOVOVIEW SP FUNCTIONAL BLOCK DIAGRAM

The Continuous Tone systems have higher capacity and better scene quality as compared to the NOVOVIEW series. The first system (CT-1) was delivered in 1973. In 1975, a CT-2 system was provided to the National Maritime Research Center for use in ocean navigation, harbor operations and docking. A CT-3 system was delivered to Johnson Space Center in 1976 and offered higher performance capability. The CT-4 and CT-5 systems are discussed below. The CT-5 system is again discussed in Section 5.

> Two flight simulators were delivered to Lufthansa in 1977. These devices can display 400 polygons and 4000 point lights. Polygons are selected for processing only if their projected size on the display exceeds a given area threshold. When an overload condition is anticipated, a data management program running in the controlling general purpose computer raises the acceptance threshold. A very quality picture is obtained by sampling the image at four subscan lines and as many subelements within each pixel, state-of-the-art edge smoothing, and a field update rate (60Hz) of the image. Lights are subjected to sophisticated filtering and raster scan conversion processing to assure the preservation of their size, shape, and brightness as they move about the raster.
>
> E&S is currently working as a subcontractor to Reflectone Inc. on two 6 channel CIG modules for use in Reflectone's CH-46E helicopter trainer. These units will display 2500 polygons at a field update rate. The trainer is designed for the U.S. Marine Corps for their twin turbine, tandem rotor helicopters, manufactured by Boeing Vertol Co. The instructor sits in a control station and can "fly" as a pilot or copilot, with limited control over the training session. The last 5 minutes of operation are recorded on tape for playback, with the accompanying instructor's voice commentary. The following types of training missions will be practiced with the simulator:

> confined area takeoffs and landings, shipboard takeoffs and landings, inclement weather operations, sling load operation, and formation flying.[7]

The capabilities of the E&S/Redifon SP-1, SP-2, and CT-5 systems are displayed in Table E-1.

McDonnell Douglas Electronics Company:

McDonnell Douglas has been offering relatively low cost, simple design CGI systems since 1971 when the first Vertical Image Takeoff and Landing (VITAL) II system was delivered. VITAL III offered a much higher resolution than VITAL II with respect to front window runway approach and landing scenes. VITAL IV systems represent McDonnell Douglas' current color, day/dusk/night CGI system.

> The VITAL IV image generator fits into a single cabinet. It consists of a general purpose computer feeding into a special purpose parallel processor called a Picture Controller. The general purpose computer takes care of all geometric transforms, hidden surface calculations, and windowing. The Picture Controller consists of a number of special purpose computers and controllers running in parallel. Its duties include beam steering and blanking, control of beam foçus and intensity, and surface shading. The Picture Controller is the heart of VITAL's calligraphic image generation approach. Its operation will be described in more detail below.
>
> Once three-dimensional objects are projected into the viewplane, they are treated as polygons. A polygon is defined in terms of its left and right edge vector outline. A polygon is scanned out by moving the electron beam back and forth between its borders. Each time the beam reaches a left or right border point, it is displaced vertically to paint out the next raster line

[7]Schachter and Ahuja, p. 28.

segment. Horizontal beam velocity and vertical separation between raster segments are carefully controlled to give a displayed surface a uniform appearance.

A conventional CRT scans out raster lines only in one direction. VITAL's ability to write a line out in both directions allows for a more efficient use of the beam deflection system. Beam position is critical when writing in the retrace mode. The very high beam deflection rates used make the brightness of a scanned surface highly dependent on beam dwell time. Horizontal deflection linearity is critical to picture quality. Variations in horizontal writing rate produce effective changes in beam dwell time, creating intensity variations. When the beam is moved from one raster line to the next, any vertical overshoot may cause the beam to overwrite a previously scanned area. Vertical undershoot reduces the uniformity of the scanned surface. If partial overwriting occurs along the left and right border of a scanned polygon, the border of the polygon will have an increased brightness. VITAL IV maintains uniformity along the border by deflecting the beam a small distance past the border, while blanking out the beam during these excursions. The excursion time outside the polygon is used to let the beam settle down before going on to the next scan line. Relative timing is of course critical. The operations of the special purpose computers and controllers which manage these tasks follow.

Image surface generation is handled by X and Y computers and a Sweep Generator. The X-computer calculates the left and right border points for each horizontally scanned surface segment. Each time the beam is moved vertically to point out the next raster line segment, the X-computer adds a Δx to the previous x border value. Since the borders of polygons are constructed from vectors, each with a slope $\Delta y/x$, the computation of Δx is a matter of simple mathematics.

The Y-computer keeps track of the current y-value of beam position. It compares the current y-position to that of the y-value of the

current border vector's endpoints. When the endpoint of a vector is reached, the proper Δx must be obtained for the succeeding border vector. When the scanning of the polygon is complete, the beam blanks out and jumps to the next polygon to be scanned out.

The Sweep Generator controls the instantaneous horizontal position of the beam.

The Z-computer receives shading coefficients from the general purpose computer. It uses these coefficients to perform a linear interpolation of the intensity values within a surface, as a function of x and y-position. One use of this computer is to provide a tapered horizon glow, fading smoothly as the angle above the horizon increases. The illumination due to landing lights is simulated by tapering the brightness of the runway surface as a function of distance from the landing aircraft.

The Focus Controller manages the focus amplifiers on the CRT's. One function is to display light points of a specified size, regardless of the colors of the lights. Beam defocus is needed to eliminate the visibility of individual lines when filled polygonal surfaces are scanned out. Defocus is used very carefully to prevent edges from losing their sharpness. Special care is taken when scanning out small polygons to keep the beam focused well enough to prevent a fuzzy appearance. For large surfaces, the combination of a lower line density and defocused beam increases scanning efficiency.[8]

Figure 4-5 is a functional block diagram of the VITAL IV system.[9]

The capabilities of VITAL IV are depicted in Table E-1. McDonnell-Douglas has delivered numerous VITAL IV systems

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[8] _Ibid._, pp. 29-30.

[9] VITAL block diagram is extracted from the VITAL IV technical description and is used with permission of McDonnell Douglas.

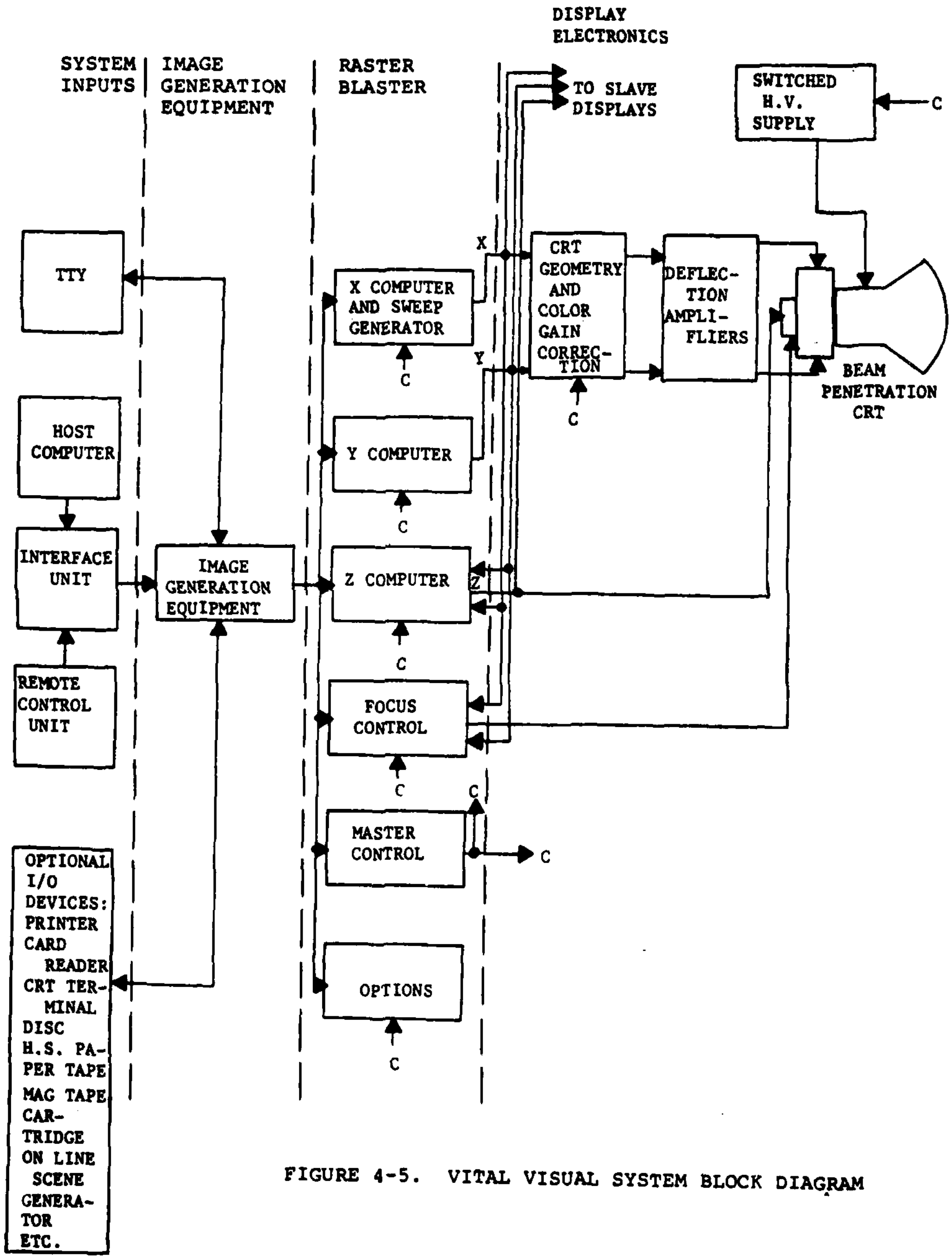

FIGURE 4-5. VITAL VISUAL SYSTEM BLOCK DIAGRAM

for inclusion in military and commercial simulators. VITAL IV systems are currently in or will be used in, Navy P-3C and F-18A simulators, U.S.M.C. A-6E simulators, and in U.S. Air Force A-10, A-7D and F-4E simulators.

Singer Company-Link Division:

Although Singer-Link has been in the flight trainer business for 50 years, they followed GE, E&S and McDonnell-Douglas in entering the CGI visual system market. After introducing their CGI visual systems in the mid-seventies, however, they have been strong in the market. Singer-Link has, or will, deliver systems for the NASA Space Shuttle Simulator, F-111, Black Hawk and the B-52. Singer-Link has also supplied a system to NASA Ames.

Singer-Link has a real time, 3 dimensional, night only calligraphic system called NVS. The system offers realistic placing and movement of lights and four colors. Singer-Link's current raster day/dusk/night systems offer a high capacity with numerous available enhancements.

> Current Singer day/dusk/night CIG systems consist of a 32 bit general purpose computer feeding special purpose hardware. The general purpose computer directs the activities of this hardware. Singer thus calls it a Digital Image Generator (DIG) Controller. The DIG Controller accepts position and attitude information from the flight computer. It also retrieves object descriptions from disk, computes occlusions, priorities, and passes this data to an active data base memory.
>
> A data base is organized into gaming areas, which are further partitioned into blocks. A block contains descriptions of all objects, terrain, and culture features residing within

its geographic limits. A cluster is a collection of objects which comprise a real world feature. Any feature may be modelled at several levels of detail. A cluster of a given level of detail is activated when the distance between its centroid and the viewpoint falls within given bounds. For example, a distant runway will first be included in a scene in a simple form, and then be replaced by successively more complex forms, as it is approached. Switching distances are controlled so that the displayed levels of detail do not oscillate when a pilot happens to fly along the threshold of the activation range.

The image generation hardware is connected to the DIG Controller through three direct memory (DMA) channels. The active data base is transferred to the active base memory through one of these channels. The content of the active data base memory is updated with changing viewpoint and attitude, as directed by the DIG Controller. All geometric processing is under software control from the DIG Controller through the second DMA channel. The image generation hardware processes 12,000 potentially visible scene edges at a 30Hz update rate. Approximately 8,000 of these edges (or edges and light points in any combination) may actually be displayed at once. Edges are smoothed in both the vertical and horizontal directions. Scintillation is minimized by reducing the contrast of faces whose projected sizes approach the pixel size.

A Frame Calculator performs four major tasks: (i) object processing - including the elimination of backward facing surfaces of potentially visible objects, (ii) rotation and illumination, (iii) windowing, and (iv) projection, edge, and boundary calculations. A Scanline Computer uses data obtained from the Frame Calculator to construct a scene on a pixel by pixel basis.

The third DMA channel transfers color data to the Video Generators.

Each optical system consists of a 25" color CRT, a spherical mirror, and a beam splitter. The spherical mirror collimates the image formed

on the CRT monitor, so that the student pilot is presented with a virtual image appearing to be at infinity.[10]

Figure 4-6 is a block diagram of Singer-Link's DIG System.[11]

In addition to the capabilities described above and in Table E-1, Singer-Link offers many special effects such as moving objects, clouds (entering and leaving) and lightning.

Other Manufacturers

The preceding discussion was limited to manufacturers with currently fielded military simulators. This does not imply that there are not other manufacturers either producing or capable of producing CGI systems. Gould, Inc., for instance, has announced its GVS-1 system, which is displayed in Table E-1. Figure 4-7 is a block diagram of Gould's GVS-1 system.[12]

Other CGI Systems

There are currently available a large variety of commercial computer graphics systems. The systems offer a wide range of features and prices. Tektronix, Calcomp, Hewlett-Packard, and Sanders Associates are just a few of the manufacturers. The Tektronix offerings range from a high

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[10] Schachter and Ahuja, p. 26.

[11] Extracted from "Technical Proposal Link Digital Visual System", Link Division, Singer Company, June 1979. The Schachter and Ahuja article contains a detailed block diagram.

[12] Extracted from Gould's response to CSC's CGI survey questionnaire.

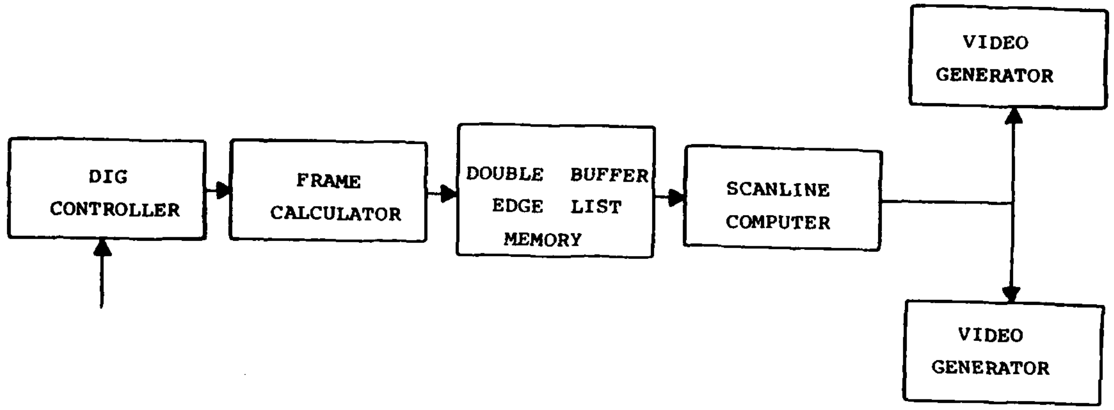

Figure 4-6. Singer-Link Image Processing Hardware

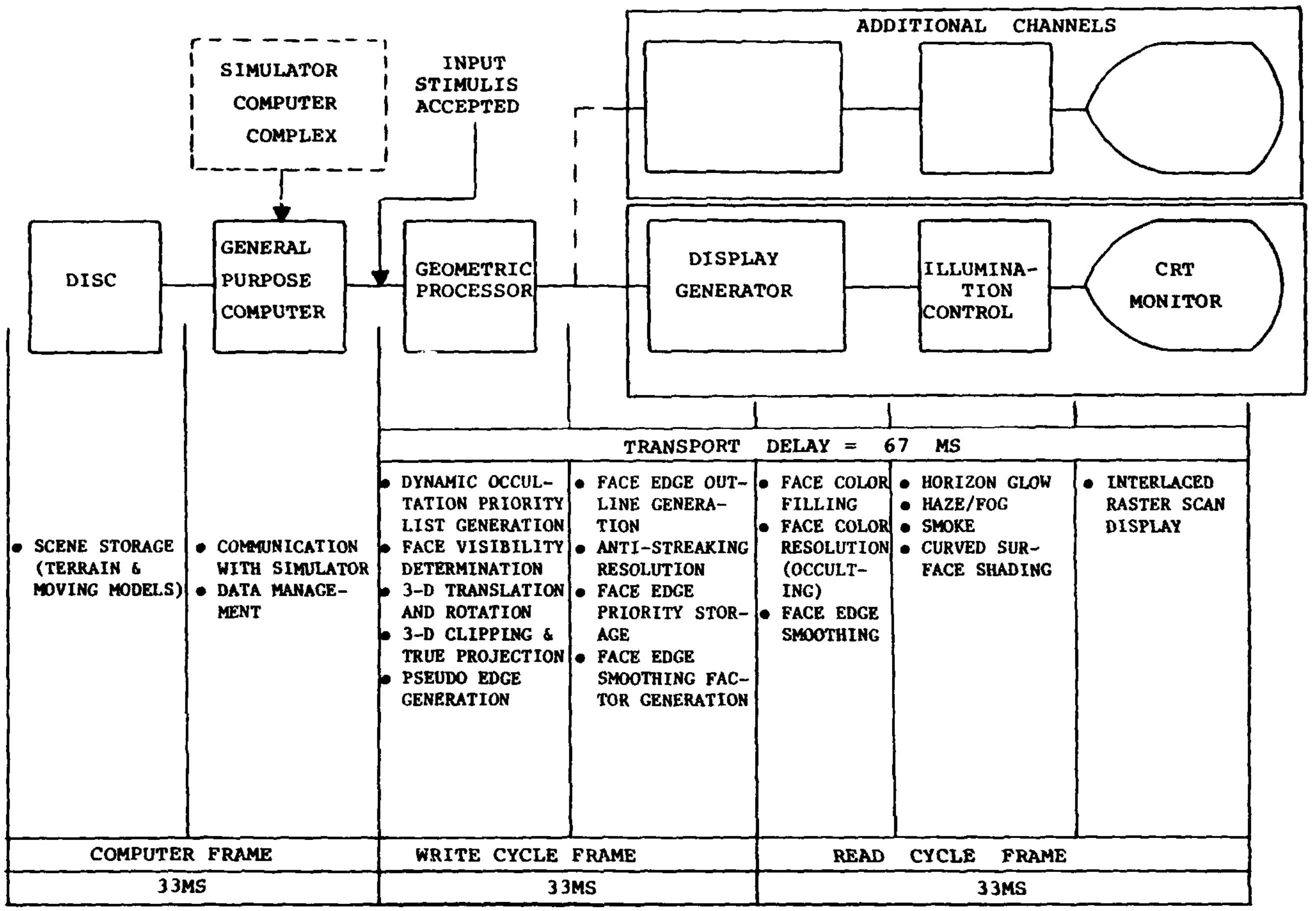

FIGURE 4-7. BLOCK DIAGRAM OF GOULD GVS-1 VISUAL SYSTEM

resolution monochrome calligraphic terminal using storage tube technology with superposed moving targets, to high resolution full color raster scan displays. These terminals are real time interactive devices, but the time required to construct a new scene (transport delay) is significant. These systems can be purchased with a wide range of add-on equipment options including disc drives, tape units, and host computer interfaces. Tektronix also has a large variety of software support packages. Not all manufacturers have the large product line Tektronix has, but the general capabilities described here apply. The CGI reference library, furnished with this report, contains product literature on most of these systems.

Although these systems are not suitable for the real time simulation problem, their display quality and system capabilities are excellent. These devices should be considered in the future for visual training tasks that do not require the full capabilities of the higher priced CGI systems. It is possible that by analyzing the training tasks simply from the viewpoint of "how can I utilize this display?" it will reveal training tasks which can be accomplished effectively and cheaply using these systems.

Technology Barriers and Constraints

Present day CGI systems do not approach real world realism in terms of resolution or picture content. However, the existing systems have proven cost effective and training effective for certain pilot training missions. Although these systems have been approved as a substitute for in-flight training of pilots for certain missions, there are training missions for which these simulators have not yet proved to be effective. These missions include nap-of-the-earth flight.

Through-put:

A single limiting factor in CGI systems today is through-put, or band-width. Machines are simply not capable of processing more numbers faster than they are at present. It is entirely possible that the failure of the present systems to do adequate nap-of-the-earth flight training is not caused by this through-put limitation. It may instead be the case that the failure is due to lack of understanding of visual <u>cueing</u> requirements. There are several studies investigating the visual cueing requirements problem. Validity of this hypotheses will not be known for quite some time, if ever.

Field of View:

CGI technology is being driven towards a wider field of view capability. There are two main thrusts to this effort. First, there is general agreement that the peripheral motion cues are important in determining speed and distance in nap-of-the-earth flight. Second, there are flight training situations where the pilots interest is to the side or above him as opposed to being in front of him. Although wider field of view can be accommodated by simply adding more channels, more windows, in CRT based systems, there are practical limits to this approach. In system architectures where edge crossing per scan line limits apply to the system and not just to the display channel, this approach is also not wise. Because peripheral cues are received in a much lower resolution than at focus point objects, it might seem that computational time could be reduced for these cues. The fact is that it will take the computer as long, or longer to compute and draw a fuzzy or blurred object, than it does to draw a sharply defined object.

One promising approach to the field of view problem involves the use of helmet-mounted displays. In this approach the visual system moves with the observers head, eliminating some of the physical constraints on obtaining very wide field of view. Unless the position of the observer's head is severely constrained, however, the computational requirements of scene generation grow rapidly with head movement.

Resolution:

Current CGI technology does not approach the resolution capabilities of the human visual system. At the present time there is no consensus as to what the minimum resolution requirement really is.

There are technical methods or strategies for providing higher resolution in small areas of the display. One method, which has its logical roots in optical target dome projection, is called insetting. In this method, a small percentage of the screen paints at a higher resolution with a detailed image of a target, or other object of interest. Problems with this approach in present uses are that the boundary area of the inset presents a strong visual cue in target acquisition. Another approach to the resolution problem is to focus high level resolution in the area on which the eye is focused. Since the resolution of the human eye drops quite sharply with angular displacement from the focus, the idea is that lower resolution can be painted away from the focus. This approach requires devices which track the position of the pilot's eye. It is certainly not clear that this area-of-interest approach

holds promise for making CGI systems faster or simpler. The system has to have a fully detailed scene within the visual range the eye can cover in the transport delay time interval. This expands considerably on the high detail area. If a two, or three crew member trainer is considered, the area of interest approach may not help at all.

The Government is currently procuring training devices with intentionally limited field-of-view, such as periscope trainers and tank trainers. The perceived (eye-point) resolution of such devices is one arc-minute or less using existing hardware systems. Such trainers might provide useful basis for evaluation of resolution requirements.

Display Devices

Historically in the CGI industry, the display device has not been the limiting factor. However, the current demand for wide field of view visual systems, coupled with the rapidly expanding capabilities of computer systems, is going to require a more advanced display device. Current color CRT technology places an absolute upper limit on the field of view one device can provide at a given resolution. For example, a 2000-line CRT used at a four arc minute line-pair resolution could provide a vertical FOV of 33^{o}. A 4000-line CRT at the same resolution could provide a 66^{o} vertical FOV and probably represents the practical limit of that technology. The optical problems presented in changing the screen display to an apparent out-the-window picture more than $88^{o} \times 66^{o}$ in size, also limits this approach. Multi-window (or channel) systems can be used

to generate the wide FOV in an additive fashion. Such approaches generate new problems of image registration and window-to-window matching. Also, problems with size and weight develop rapidly for trainers with motion bases as more windows are added.

Current technology is exploring the use of lasers and other high technology devices as CGI display devices. The possible resolution obtainable with such a system is almost unlimited. However, present systems are limited by the image generation function. The technical problems of these systems (diffraction, light scattering, etc.) are being addressed, but are not completely solved.

Display Generation

The display generation process is the synthesis of display device control signals from the computer translated image data. This generally involves the reading of computer data from a frame or line buffer and using digital to analog conversion techniques to generate color and intensity control signals. In a calligraphic system this would also include generation of positioning and deflection controls. This area does not appear to be a limiting factor with current technology, although the total data through-put rate is staggering. For example, a 1000 line raster scan system refreshed at 30 times/second handles 30 million picture elements/second. This capability is just within the range of current technology, with respect to digital to analog conversion, as well as memory access technology. The digital and analog signals required here are radio frequency signals which require careful, but not exotic,

circuit design and construction. As laser display devices come into more use, video bandwidths of 100 MHz and higher will require more sophisticated handling, but will not be pushing any severe technological limit.

Cueing Requirements

If the visual simulation industry has a fatal flaw, it is the lack of understanding of cueing requirements. Much study is currently under way in this area. Considering the complexity of the human visual and behavioral system, it is sometimes surprising how much is known.

The school of thought that attempts to quantify human performance in terms of digital through-put, is advancing some sensible ideas. The low numbers they provide for human capabilities may ultimately result in simplification of CGI system requirements. However, further research may indicate that the human visual system processes such a large number of stimuli in parallel that no simplifications are possible.

Game Strategy

Behavioral scientists show concern in flight simulators about artificial cues or the development of game strategies unrelated to real flight situations. It might be possible that transferable training can be taught on video arcade type devices playing artificial games. There are certainly hand-eye coordination tasks which can be learned on such a device. Any applicability to pilot training is unknown.

Scene Complexity

Scene complexity, or lack thereof, is currently the major CGI limitation. While many approaches to adding complexity to a scene are being tried, no one solution has been found. There are in existence algorithms for generating highly complex CGI visuals. However, they do not operate in real time. Texturing algorithms have been devised to artifically add scene details, as opposed to storing all the details in the data base description of the scene. Curved surface shading algorithms have also been developed as methods of adding visual information to the display without raising computational loads. Further work and study on CGI algorithms may yield methods which will significantly increase perceived scene details without significantly increased loading on present systems.

This section has offered that the current state-of-the-art in CGI visual system technology is, indeed, impressive. There are at least four vendors currently offering a wide range of basic visual systems which can be supplemented by a variety of enhancements for special features and/or needs. These four companies should be joined by others in the near- to mid-term.

SECTION 5

FUTURE TECHNOLOGY

Attempting to predict future CGI technology is risky, at best. However, a look at what has been done, helps reveal what can be done; a look at current developmental efforts, is a look at future off-the-shelf technology; and a look at current needs is a look at future capabilities.

Generally, the near-term picture for CGI visual technology is incremental versus quantum in nature. The mid-term and long-term, however, should see quantum leaps in the capabilities of CGI systems due to current efforts, needs and competition. The remainder of this section will discuss general trends in CGI technology, and recommend areas which should be monitored in order to maintain a base of knowledge concerning trends and anticipated capabilities in CGI visual technology.

General CGI Trends

"Higher edge capacities is inevitable. Current manufacturers have implied that edge capacity will more than likely double or triple over the next 2 to 3 years".[1] Figure 5-1[2] depicts the dramatic increases in edge capacity that have taken place since 1964, and projects this trend into the future. The projected edge capacities over the next few years seem attainable, based on past increases, and seem to hold great potential for the provision of greater density and higher complexity scenes such as those encountered in NOE flight. This

[1] U.S. Air Force Flight Dynamics Laboratory "CIG Applications Study", p. 324.

[2] *Ibid.*, p. 344.

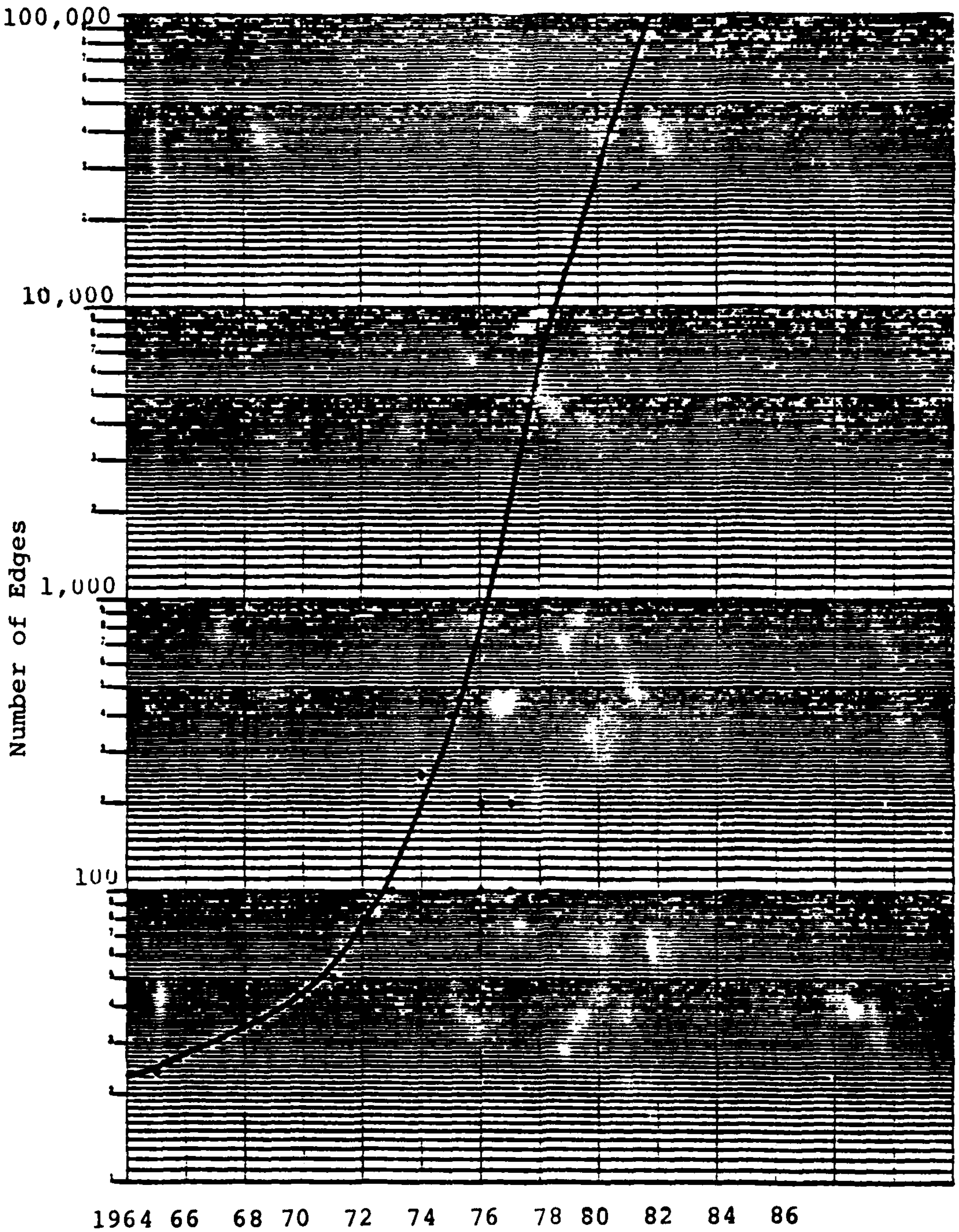

Figure 5-1 System Edge Capacities
(USAF-FLD/LOGICON, 1980)

potential, however, is somewhat dimmed when other parallel factors such as transport delay and data base generation problems are considered.

Figure 5-2[3] graphs the relative number of operations required as a function of visible edges, by the various competitive image generation algorithms being used today. To be noted is the fact that, except for algorithm (6), increases in visible edges translate into dramatic increases in the number of computations required to furnish those edges. Each computation consumes time and, thus, is a contributor to transport delay. Considering that 100 ms is generally perceived to be the maximum transport delay that can be tolerated before the trainee consciously notices that delay, one can see that with current hardware, architectures and algorithms, increases in edge capacity are limited by the transport delay that can be tolerated. Algorithm (6) represents the efforts of the Ohio State University Computer Graphics Research Group which includes Dr. Csuri and others who are currently under contract to NTEC. This new approach, while exhibiting promise, has not been implemented in real-time, however, "its implied potential is 100,000 to 300,000 edges".[4]

In addition to the transport delay issues discussed above, data base generation restrictions also arise as edge capacities increase and the required gaming area expands. As stated by Gullen (1980) in the USAF-FDL CIG Application Study, "the additional capacity may well be useless unless a much more efficient method of data base building is utilized".

It is the opinion of CSC that newer, faster, more efficient

[3] Ibid., p. 343.
[4] Ibid., p. 342.

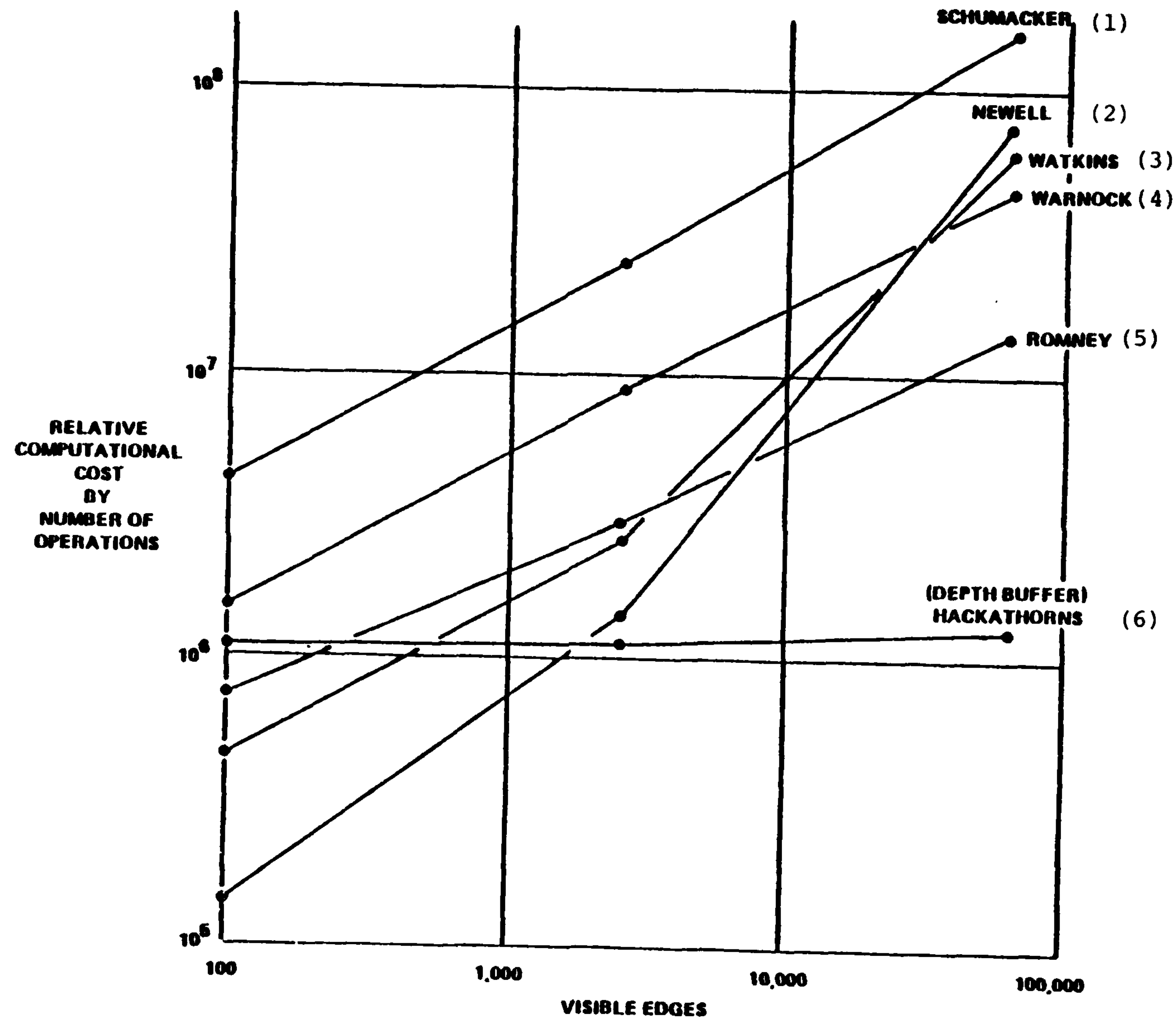

Figure 5-2 Competitive CGI Algorithms
(USAF-FDL/LOGICON, 1980)

(hopefully less costly) data base generation techniques will become available over the near- to mid-term. This capability will be forced by multiple pressures. The first pressures arise with the incremental increases in the capacities of systems (in terms of edges), as discussed in the previous paragraph. Between increases in capacity and increases in gaming area, data base generation techniques will improve.[5] Stated user requirements is a second area of pressure which will cause improvements in data base techniques. This is already evident in the B-52 and C-130 programs and will be further exhibited in the Army/NASA Ames effort. The final area of pressure influencing data base generation techniques is inevitable and omnipresent--competition. (See the discussions in this section under current Government efforts for a description of NTEC N-74 Projects 8741 and 8742.)

The near-term will see better and more efficient texture generation methods. Marconi's texture methods are notable among these efforts according to several interviewees of this study effort. There are also efforts by Mr. Loren Carpenter (Boeing Computer Services), Dr. Lucido (formerly with Texas A&M, now with Intercomp Graphics in Houston) and Dr. Fournier (soon to be with the University of Toronto) involving the use of fractals. Fractals are based on the mathematical properties of natural forms and are used to provide much greater detail in CGI scenes.[6] None of these efforts have as yet been implemented in real-time, although implementation may occur in the near-term.

[5]There is, of course, an alternative to this dilemma. Users could opt for smaller and/or less detailed data bases as a trade-off. This, however, assumes that users put more effort into the areas of training needs analysis and define system performance requirements in terms of training requirements versus technical performance (i.e., edges, color, levels of detail, etc.).

[6]The interested reader should consult the Proceedings of SIGGRAPH "80" for further information on Fractals.

Excerpts from two recent efforts can be used to summarize the general trends in future CGI technology:

> Development of a CGI system from inception to a working hardware implementation appears to take approximately three years. This three-year cycle time would probably be a good rule of thumb to be aware of when considering future approaches. In addition to those future manufacturers mentioned previously in this report (i.e., ATS, Gould, Grumman, and Marconi), there are other individuals and groups working on future CIG approaches (e.g., the Defense Engineering Division of Chrysler Corporation, D. Cohen at USC Information Sciences Institute, Boeing collaboration with Computer Graphics Research Group, etc.).
>
> The Boeing collaboration approach is of interest because of its high potential for a greater than one order of magnitude increase in system capacity, as well as automated data base building potential.
>
> Cohen's approach is of interest because of its simplicity of implementation and the fact that E&S, GE and Link are interested in it.
>
> Other work continues to be done in computer graphics at universities across the nation. The future impact of this research cannot be predicted.
>
> With the exception of the Cohen approach, it seems unlikely that the current CIG manufacturers will push for a major breakthrough in CIG technology. Their past performance implies an orderly evolution from earlier work, rather than a revolution.[7]

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[7] USAF-FDL Report, "CIG Applications Study", p. 346.

> The optical disk will eventually replace the magnetic disk as a means of storing digital data bases. One approach places an optical and magnetic disk in tandem. The optical disk contains the permanent data base for a large environment. The magnetic disk holds the director, and any updates and corrections to the data base.
>
> The future of image generation hardware lies with VLSI circuitry. One architecture receiving considerable interest is that of Cohen and Demetrescu. Their design uses a separate VLSI chip to handle the processing for each polygon in a scene. An image generator displaying several thousand polygons will have several thousand of these chips. The result is simplicity in construction and speed due to parallelism.
>
> Holographic approaches are again sparking interest for image display. Farrand Optical Co. has already demonstrated a Holographic Pancake Window. Other areas of research include laser scan displays and fiber optic bundles to carry images right to the goggles worn by the pilot.[8]

The Cohen approach being addressed above is his Very Large Scale Integration (VSLI) approach which was presented at the First Interservice/Industry Conference in November 1979 and is contained in an appendix to his NTEC report on CGI technology.[9] The Boeing approach was addressed by Mr. Michael Cyrus in a briefing to PMTRADE on July 11, 1980.

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[8]Schachter, B. and N. Ahuja, "A History of Visual Flight Simulation", Computer Graphics World, Volume 3, #3, May/June 1980, p. 31.

[9]NTEC Technical Report 77-C-0154-1, "Summary of the CIG Survey", February 1980.

Monitoring CGI Technology and Trends

In order to maintain a base of knowledge concerning CGI technology and anticipated capabilities, PMTRADE should:

- Maintain a knowledge of, and contact with, CIG vendor's efforts, especially the efforts of those in the vanguard of CGI technology.

- Monitor ongoing efforts, needs and agencies with respect to CGI visual systems, especially those efforts that tax current capabilities.

- Obtain the results of Government sponsored reports, surveys and/or studies in the CGI visual arena.

- Monitor current CGI topics addressed at professional seminars and conferences, and in papers, documents and other publications. This can be accomplished either through attendance at these events, or by subscribing to the published proceedings, journals or other sources of such information.

Current Vendor Efforts:

Evans and Sutherland/Redifon, General Electric, McDonnell Douglas and Singer-Link are vanguard vendors of which PMTRADE must maintain a knowledge. The vanguard, however, may change over the near- to mid-term time frames (by additions versus deletions).

Gould, for example, is now a prime CGI vendor with their GVS-1 system; Marconi, especially their dynamic texture efforts, offers much potential; Boeing has embarked on an internal, high edge capacity, R&D effort; and, the ATS effort may mature.

ATS is a New Jersey based division of the Austin Company. Their first CIG device was a night only visual simulator for navigating a ship through a harbor. It displays 300 point lights (colored, hooded, and blinking).

ATS has recently completed the development of a sophisticated day/dusk/night visual simulator called COMPUTROL. They claim to have a flexible design which allows for the display of anywhere from 8,000 to 100,000 edges and around 100,000 point lights. Since this device has not yet been used in a training program, little can be said about the success of their design.

Unlike other visual simulators, COMPUTROL does not use a general purpose computer. A custom design CPU unit controls special purpose image generation and display hardware. (See Figure 5-3[10])

An Image Generator consists of two parallel processors: a Projection Processor and a Visible Surface Processor. Each processor consists of very high speed controllers and arithmetic units which communicate with the CPU and main memory. The Projection Processor has three subunits: (1) a floating point array processor, (2) Edge Assembler and Clipper, and (3) a data cache. The Visible Surface Processor consists of four subunits: (1) a fixed point processor, (2) data cache (visible and current edge buffer), (3) visible surface decoder and edge sorter, and (4) visible edge encoder.

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[10] ATS Block Diagram extracted from Swallow, R., R. Goodwin and R. Drandin, "Computrol Computer Generated Day/Dusk/Night Image Display", Proceedings of the 11th NTEC/Industry Conference, Orlando, Florida, November 1978, p. 323.

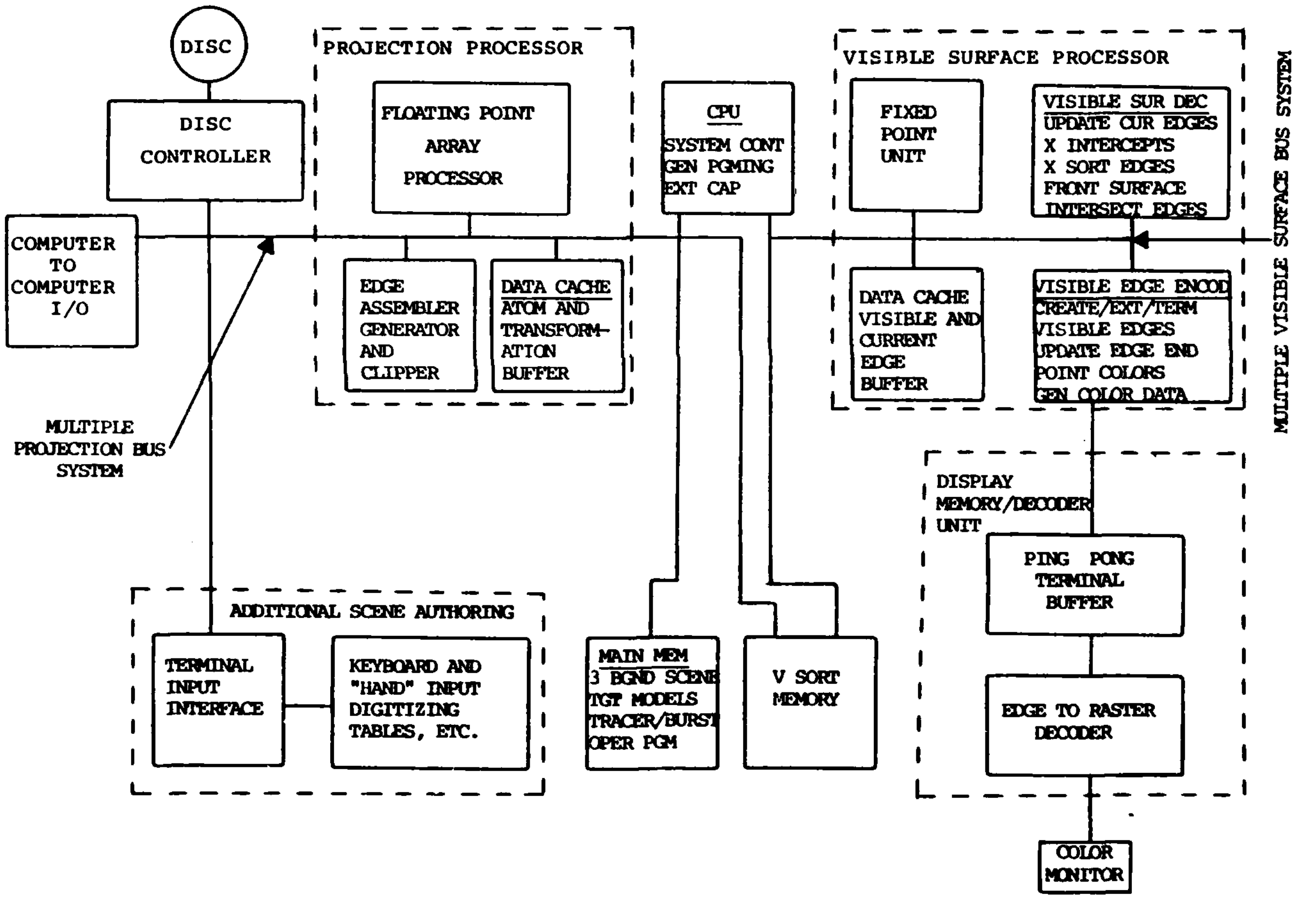

Figure 5-3. ATS Image Generation Hardware

The Image Generator feeds into a Display Memory and Edge-to-Raster Decoder Unit. This unit receives edges from the Image Generator representing the two-dimensional projections of three-dimensional scenes. It buffers and converts these edges into analog video for a color monitor.[11]

Table E-2, Item number 1 (Appendix E) is a description of the ATS proposed system.

Current Government Efforts:

Within the Government, PMTRADE should monitor ongoing efforts and needs (which will eventually translate into efforts), and should maintain liaison with selected agencies/activities. Primary efforts that should be monitored are those that tax the current state-of-the-art and/or call for new, innovative or unique efforts in specific areas such as data base, edge capacity, FOV, texture, tiling, projection techniques, etc.

Air Force projects which should be monitored are the B-52/C-130 projects (Table E-2, Items 2, 3 and 4) and Project 2363, especially with respect to its non-edge based techniques. A non-hardware effort which bears watching is the Integrated Cuing Requirements effort by the Aeromedical Research Laboratories at Wright-Patterson AFB. This project has been converted to a joint service effort and may result in the information needed to specify CGI systems in terms of training needs versus technical requirements, a change which most vendors would probably welcome. The Marine Corps CH-46 simulator is a project which will take advantage of the latest E&S/Redifon offering in an eight channel configuration (Table E-2, Item 5). The Army/NASA Ames Advanced Cab and

[11]Schachter and Ahuja, pp. 30-31.

Visual System (ACAVS) is an example of a current need (Rotor-craft NOE flight training) which is transitioning into an effort that may well result in new technologies or techniques. The ACAVS system is described in Table E-2, Item 6. This project could result in advancing the state-of-the-art with respect to FOV, real-time high density scenes, and data base techniques. The Naval Training Equipment Center (NTEC), Code N732 (Visual Technology Research Simulator (VTRS) Facility) is continually performing efforts involving FOV, perception and cuing, and offers a valuable source of technological information. The capabilities of the VTRS system are displayed in Table E-2, Items 7, 8 and 9. NTEC Code N74 efforts, especially projects 8741 and 8742, offer great potential for the development of new, innovative, needed techniques in the near- to mid-term. Project 8741 is a Low Level Daytime CGI project involving an unstructured 3-D calligraphic data base, a structured interactive data base for VTRS, a sensor/visual data base and a real-world shoreline data base. Project 8742 is being accomplished, at least in part, through a joint DMA/NTEC effort. 8742 is an automated CGI data base effort involving data base language constructs for CGI graphics, a problem oriented language for VTRS, a universal data base with display procedures and a transformation program to produce VTRS data bases from a DMA data base. The Navy also has a wide variety of simulators currently fielded, under development or in planning. Table E-3 contains a listing of current and proposed Navy simulators that do or will contain visual systems.

The following Government offices/agencies offer a readily available base of knowledge concerning all aspects of CGI technology and, therefore, must be considered for the maintenance of close liaison:

NASA Ames/U.S. Army Aeromechanical Laboratory
* NTEC - N214
* NTEC - N732
* NTEC - N74
USAF-AMRL (Integrated Cuing Requirements)
USAF-ASD (SIMSPO)
USAF-HRL

Government Sponsored Reports, Surveys and/or Studies:

Recent results of Government sponsored reports, surveys and/or studies in the area of CGI technology in general, or specific topics within CGI, can provide PMTRADE with a valuable source of current information. Some recent examples which should be consulted are:

- NASA Ames/Army (Boeing), "Conceptual Design Study For An Advanced Cab and Visual System", Contract NAS2-10464, Preliminary, July 1980.

- NTEC (USC) Technical Report 77-C-0154-1, "Summary Of the CIG Survey", Draft, February 1980.

*These offices are geographically co-located with PMTRADE and can offer invaluable current technology assistance. In fact, according to some industry personnel, the NTEC Codes of N732 (VTRS) and N74 should provide the best R&D facility for CGI available by the end of this year.

- USAF-FDL (Logicon) Report, "CIG Applications Study", Draft, March 1980.

- USAF-TAWC, "Follow-On Simulator Comparative Evaluation", Final Report, May 1979.

Outputs from the Joint Technical Coordinating Group "JTCG/SATD Roadmap Through CIG Technology" with its project description attachments has the potential to be a very valuable technology information source document.

Current CGI Topics:

There are numerous sources of current CGI topics which address ongoing and proposed technologies/techniques. The more apparent examples are the Interservice/Industry Training Conference (November 1980, Salt Lake City, UT), the ACM "SIGGRAPH" Conference (July 1981, Houston, TX), and the AIAA "Simulation Technology Conference" (June 1981, Long Beach, CA). The Society of Photo-optical and Instrumentation Engineers (SPIE) also sponsors an annual "Simulators and Simulation" Conference. Other sources are the numerous periodicals available such as Computer Graphics World (source of much of the quoted information in Sections 4 and 5), and the International Commercial Airlines Organization (ICAO) publication.

Academia offers another potential source of technology information, especially with respect to "blue sky" efforts. Appendix C lists some of the universities that CSC found engaged in various CGI efforts.

In summary, the near-term outlook for general CGI trends is incremental versus quantum. In addition, there are numerous sources of information on current and anticipated CGI capabilities available to PMTRADE. Notable among these are NTEC sources (N214, N732, N74), the vendors and, last but not least, Appendix C to this report.

SECTION 6

CGI COST METRICS

Within the CGI visual cost arena, PMTRADE must consider two basic types of cost metrics:

- Cost Estimation of CGI Requirements

- Technical/Cost Trade-off Analyses

General Costing Philosophies

Basic knowledge is a departure point for advanced knowledge; therefore, this section will provide a general discussion of costing before discussing CGI in particular. Cost estimates will vary in expected accuracy with the phase of the project, and may consider either initial costs, consequential costs or total costs.[1] Initial costs are, basically, procurement costs. Consequential costs are the costs of ownership, support costs, or operations and maintenance (O&M) costs. The totality of initial and consequential costs represent system Life Cycle Costs (LCC). The first complete costing accomplished for any project normally becomes the base of departure or revision for future updates and, thus, it is called the Baseline Cost Estimate (BCE). As the project proceeds through its life cycle, and in support of future decision points (milestones), the updates to BCE are expected to increase in accuracy. During this process alternative

[1] Initial and consequential costs are terms used in the Department of Defense (DOD) Life Cycle Costing Guide for System Acquisitions (LCC-3), Interim, dated January 1973.

system or subsystem solutions may be considered in response to stated requirements. Providing the benefits received from (or the capabilities of) each alternative are the same, then cost becomes the driver in alternative selection. Figure 6-1 depicts this situation (Based on LCC-3, Figure 2-1).

Figure 6-1 clearly shows that had a decision been made on initial costs alone, B would have been selected, but would not have been the correct solution based on an expected eight (8) year field life. Figure 6-1 also depicts, however, that if the expected useful, or field, life of the project was five (5) versus eight (8) years, B then becomes the more attractive candidate.

Trade-off Analysis

When the benefits received (or capabilities of) alternative solutions are variable (i.e., B provides more capabilities than A, assuming these capabilities can be beneficially used) trade-off analyses must be conducted. Figure 6-2 provides four examples based on the criteria of LCC and CGI capability (based on an LCC-3, Figure 2-2).

In Figure 6-2a, A is the preferable alternative since it costs less for equal capabilities. Figure 6-2b represents the opposite of 6-2a and A is still preferable since it offers greater capabilities for equal cost. Again this assumes that benefit can be gained from the additional capability. In Figure 6-2c, A is still ahead because of more capabilities for less cost. In Figure 6-2d, A is

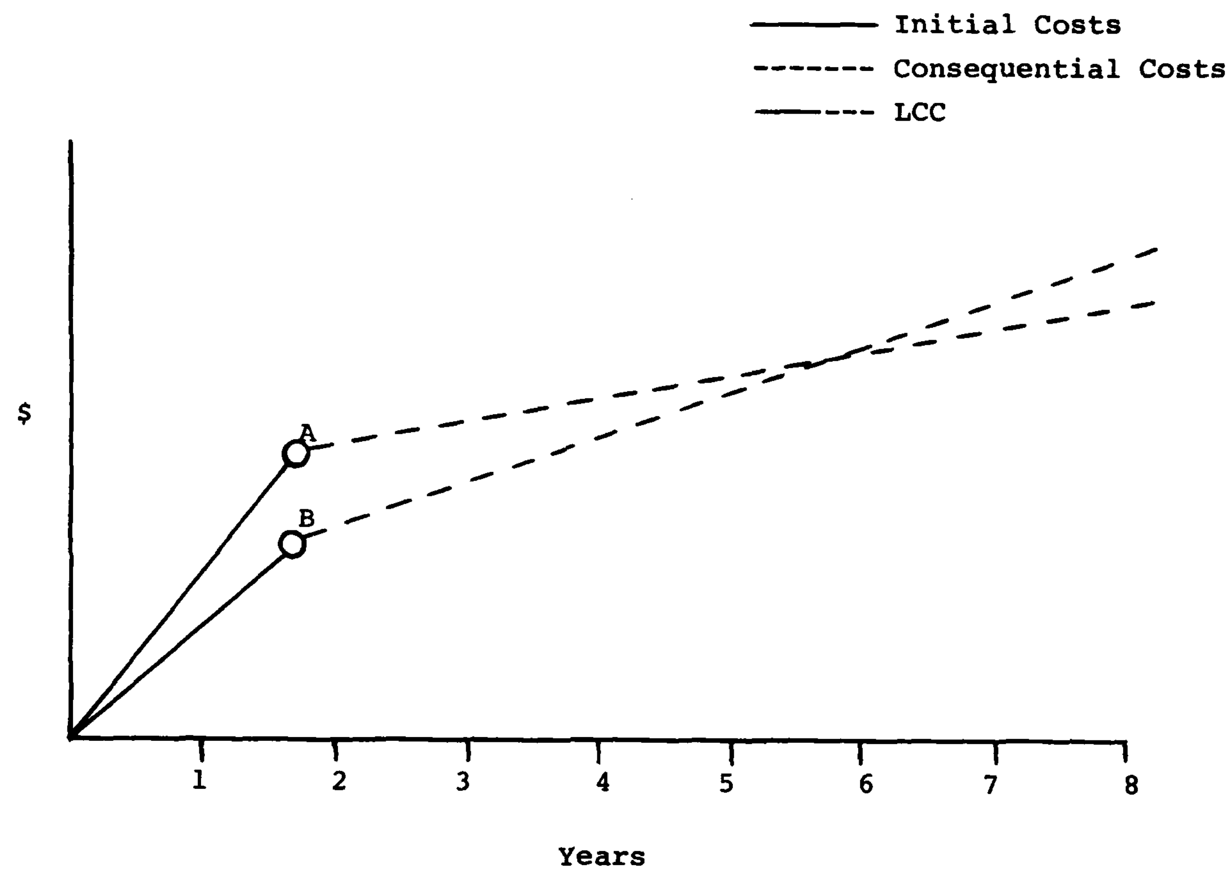

Figure 6-1. LCC COSTING

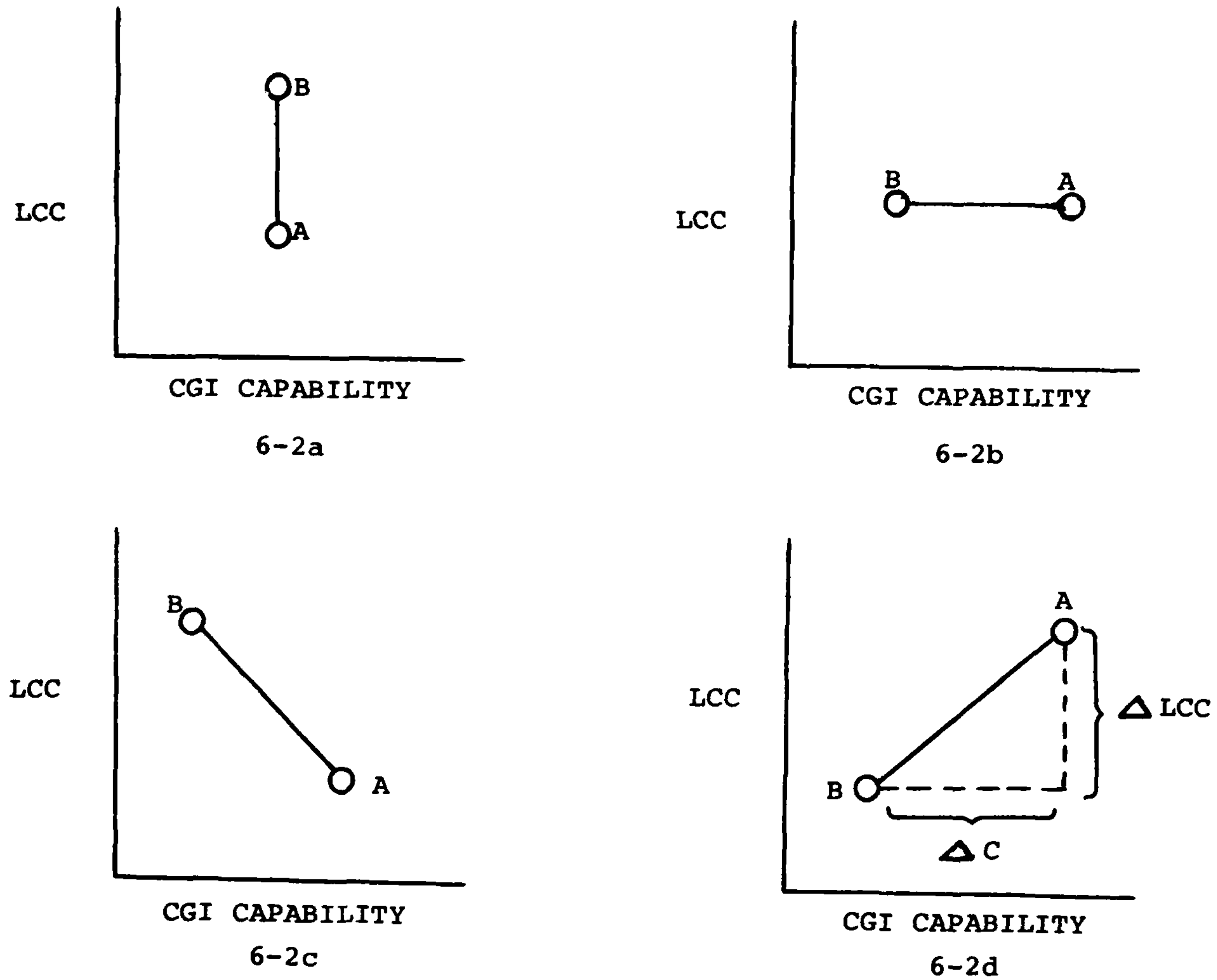

Figure 6-2. Trade-off Analysis

only preferable if ΔLCC is worth more than Δ C.[2] Trade-off analyses are generally not required where a particular solution is dominant, when all applicable criteria are considered.

Costing Methods versus Models

There are various techniques for cost estimation. These techniques may be either models or methods. The following extract from a U.S. Department of Commerce document is provided as a general discussion of models versus methods. If the reader substitutes system or simulator each time the word software is encountered, the passage becomes very applicable.

> A model purports to describe how and where a software project uses money whereas a method gives directions as to how to produce a cost estimate. One can employ a model to produce the contents of an estimate by attempting to analyze a software project in terms of the model. Or, one can employ a method which gives directions as to the form and use of documents and or supporting material needed for an estimate. Models dictate contents but allow presentation in whatever form is desired; methods dictate form, and force consistency among the several parts of documents, but allow the contents of the cost estimate to vary widely according to the estimator's judgement. Given the current state of the cost estimating art, models tend to oversimplify the problem in order to tackle it, while methods tend to place an overly large burden for tackling the problem onto the cost estimator.

---

[2] Within CGI, a total system capability worth (with respect to effectiveness) may not be valid since CGI capabilities are defined in terms of a multitude of variables (i.e., data base edges, displayed edges, resolution, FOV, colors, moving objects, etc.). On the other hand, a model such as that used by Boeing in Section 7 of their ACAVS study for NASA Ames may allow for total system consideration. The alternative is to trade-off each capability, which also creates problems to be discussed later in this section.

Software cost models are usually of two types, aggregated and disaggregated. In aggregated estimation modeling, the total cost is first derived and then appropriate percentages are allocated to each part of the software development. The allocation may be according to phases, activities, or products. Each part can then be further divided into subparts and costs allocated in a top-down fashion. In disaggregated estimation modeling, the software project is decomposed top-down as before, but costing is not applied until the total subset of software pieces are of "manageable size". Costing these pieces is presumed to be easier whenever analogous experience with similar completed small pieces can be found. Once the pieces are costed, the total cost is then derived in a bottom-up fashion. Aggregated estimation is by far the easier because it appears to be simpler to allocate costs via percentages than via absolutes. Unfortunately, aggregated estimation does not reveal how the original total cost is to be derived, and this number is generally the most difficult to determine reliably. Disaggregated estimation is more difficult because the process of independently costing each piece resulting from the decomposition seems to require more ability, confidence, and effort in detailing design considerations. However, more confidence can be placed in the results of disaggregated estimation. In practice there is probably a use for both techniques. Aggregated estimation should be used for quick, "seat-of-the-pants" guessing in preliminary planning while disaggregated estimation should be used for formal cost preparation. A cost estimation technique, whether it be a model or method, must consider constraints and trade-off inherent in the specific development effort. The major constraints encountered during software development are constraints in hardware (generally from limited memory or limited execution speed), constraints in schedule, and constraints in man-hours. If any of these constraints are stringent, the quality of the software product and/or allocated resources will be impacted. Ideally, a cost estimation technique should be constructed to provide accurate cost estimates of the various trade-offs. Unfortunately, this capability is found in few techniques.[3]

[3] U.S. Department of Commerce Software Acquisitions Management Guidebook: Cost Estimation and Measurement, AD/A-055-574, March 1978, p. 54

Cost Estimation Techniques

There are a number of cost estimation techniques being commonly used both in the Government and within industry. These techniques may be either methods or models as discussed previously. The techniques that will be briefly discussed in this section are:

- Analogy
- Rules of Thumb
- Parametric Equations

Analogy:

This technique is widely used and involves the estimation of cost based on one or more similar type efforts for which there is cost data available, or for which the cost estimator has enough intimate, recallable knowledge to provide the analogy. The cost data base needed, especially if subsystem costs or trade-offs are being considered must be detailed to the same level as the effort being costed. In the CGI arena, historical visual system or subsystem data is virtually unavailable. Within a total trainer/simulator the Work Breakdown Structure (WBS) normally does not require breakout at that level, therefore; the cost data required for analogy is generally not available. "Since this estimating method depends upon data obtained from similar projects, it is valid only when supported by a cost element data base that contains cost data as well as a selective set of each development project's hardware/software/schedule characteristics."[4] The lack of

[4] *Ibid.*, p. 31.

this data is, in fact, the subject of much of this method s criticism. Analogous cost estimates are "ballpark" at best due to the constant changes in hardware technology and costs and the fact that virtually no new military training requirement is completely comparable to a previous effort. The personnel of NTEC Engineering and USAF-SIMSPO may provide a basis of knowledge for attempts at analogous cost estimating by PMTRADE.

Rules of Thumb:

Rules of Thumb represent general experience, individual or collective, and, although many are found to be quite accurate, are to be used with caution. A commonly used rule of thumb is to estimate the cost of new aircraft based on weight (i.e., use $100 per pound X the estimated weight of the new aircraft). A rule of thumb for CGI visual systems may be, for instance, that any full capability color raster visual will cost $1.5M. Discussions with vendors during this study effort revealed that they generally felt that CGI visual systems of equal capability cost the same and that cost is around $1.5M.

Parametric Equations:

Parametric equations are mathematical representations which utilize variables, or parameters, drawn from the quantifiable experiences of previous efforts. Parametric models relate cost to cost variables and are, therefore, dependent on a detailed analysis of project variables and previous efforts. This analysis may reveal data which can be related to certain attributes. Where this occurs Cost Estimating Relationships (CERs), a form of parametric equation, may be established.

"If there are prior hardware systems which can be compared with the new (proposed) system, and if physical, performance, and cost data are available on the older systems, then statistical analysis may provide useful cost projections. Through curve-fitting techniques, system cost may be related to a combination of measures of the system (its dimensions, performance, etc.). Similarly, cost of some types of subsystems may be related to their physical and performance attributes. The relationships established are commonly called "Cost Estimating Relationships." The method is sometimes called "Parametric Costing," because the physical and performance measures are commonly called parameters in the estimating equations."[5]

Developing a CER

By understanding the manner in which a CER is developed, the reader should become aware of the data required in this, and most other, cost methods/models. The CER development information was taken from paragraph 4.3 of the Department of Commerce Guidebook referenced on page 6-5.

- Designate the Dependent Variable. Since cost data for CERs should be collected via the Work Breakdown Structure (WBS), this step includes determining which item at what WBS level should a desired type and quantity of cost data be collected for use in subsequent analysis. Difficulty in deciding the usefulness of a component or functional cost subdivision can be expected.

- Define the Designated Dependent Variable. This task includes precisely defining the designated dependent variable identified in the preceding task. Because of imprecise definitions, differing unit terminology, alternative methods of defining costs, and incompatibility of historical cost data reported by contractors and Government, the definition process is often difficult.

[5] DOD, LCC-3, p. 3-3.

- Select the Parameters to be Tested as Potential Independent Variables in the CER. The selection of technical parameters to be statistically tested, should be obtained from expert sources, and possess the following qualities:

  - Measurable in quantifiable terms
  - Available for data collection
  - Reflect performance characteristics rather than design characteristics

  In addition, when the variables reflect aspects of new technology, extrapolation of costs will be necessary.

- Collect Data on the Independent and Dependent Variables to be Correlated. The data collection task is a lengthy and difficult task which must ensure adequate quantities of comparable, relevant, and high quality data.

- Using Statistical Analysis, Explore Relationships between the Independent and Dependent Variables. This step includes identifying the logical relationship between the dependent variable and one or more independent variables. Various statistical methods of analysis are useful, including scatter diagram association and correlation coefficients, which eventually result in formulating a preliminary functional relationship from one or more candidate relationships.

- Determine the Relationship that Best Describes the Data. This step includes estimating values for parameters in the candidate relationships and choosing the relationship that best describes the data. (Least squares is a useful curve-fitting technique which is readily available in automated form via regression analysis programs.)

- Document the Results. This step includes recording relevant data about the CER in order for the CER to be used reliably by others in costing other systems or resolving problems.

Attachment 1 to Appendix A (Page A-24) is a definition of cost related terms and is intended as a supplement to the general costing philosophy material just presented.

CGI and Costing

When considering CGI visual systems for any of the previously discussed methods or models, the nature of CGI must be investigated.

CGI has some uniqueness which must be considered. CGI, compared to most other system arenas (such as communications, vehicles, weapons), is relatively new and rapidly advancing. This newness, combined with the competitive drive to quickly provide systems to suit salable needs, has resulted in a situation where there is no standardized architecture, hardware or software, and the various vendor's implementation techniques are noncompatible. This noncompatibility is present not only from vendor to vendor, but may also exist within a single vendor's product line.

The above situation impacts directly on subsystem technical/cost trade-off analyses. The subsystems of CGI are data base, image generation and display. Because of the unique implementations discussed above, trade-offs between data base (including generation techniques) and image generation subsystems cannot be considered. Therefore, the only item subject to trade-off is the display subsystem.

The potential purchaser of a visual system could analyze total requirements and design the display system needed so that he could specify it in terms of phosphor, number of lines, brightness, contrast, etc. Cohen, in his "Summary of the CIG Survey" suggests that this may be desirable since previous unbundling experiences have shown benefits to the customer. The other side of this point is that vendors have gone to considerable effort to technically match displays to the other two visual subsystems. Cohen suggests that "it is not practical now to procure separately the image generators system and the image display system".

The same discussion relating to the matching of displays with image generation systems can be applied to other features of CGI visual systems but with even more constraints. Consideration cannot be given to trading off a particular vendors three-dimentional texture for another. The uniqueness of implementation permeates throughout a systems' architecture.

Some of the vendors interviewed by CSC felt that the VLSI technology, previously discussed, may impact system architecture in the mid- to long-term timeframe and allow for some consideration of subsystem trade-offs. At the present time, however, technical/cost trade-offs at the subsystem level are not deemed feasible.

Other CGI system areas of consideration for cost trade-offs are features such as color, FOV, texture, curved surface shading, level of detail management, etc. Analyses may be conducted where the object is to consider cost trade-off relating to features. Again, because of the various

implementation techniques, an "across-the-board" features/ cost table cannot be produced. Such a table would have to be vendor unique and even then it would have inadequacies. Some features, for instance, interact with each other in the image generation system to the point that exact dollars cannot be assigned to two features and be traded off against each other. The following example depicts this:

> Feature A uses 11 processes in the image generator and costs X. Feature B utilizes 8 processes, 6 of which are common to A and costs Y. When used together the total number of process required is
>
> $$P_a+P_b-P_s=P_t$$
>
> Where P_a is processes attributed to A, P_b is processes attributed to B, P_s are those processes common to both, and P_t is the total processes required.
>
> One can also see that if A is already required, the cost to add B is not Y but Y minus the cost of the common processes.

The assignment of costs to visual system variables is not a simple matter. It is complicated by the interactions within a particular system and varies from system to system adding further complication. This fact was amply stated by Singer-Link in their response to the CGI survey questionnaire used for this study. They stated "each visual system has

different cost drivers based on its application". The continuous advances in implementation techniques used by the various CGI vendors will cause the dollars assigned to variables to change relatively quickly.

Other items affect the utilization of costing techniques, especially, automated techniques when doing LCC costing of CGI systems. For instance, one of the largest single buys of similar simulators in the military environment is the S-L F-111 system (10). Because of this, learning curves and economies of scale relating to production, fielding, training and operation do not come into play. With its expected large quantity of buy, the XM1 conduct of fire trainer, a PMTRADE effort, may provide the first opportunity to apply some of the subjects just mentioned to a visual system simulator.

CGI Cost Drivers

While there are factors which inhibit the production of easily formulated, utilized and maintained cost models relative to CGI visual systems, there are certain items that do generally come into play across vendor lines. These items are cost drivers, and represent system capabilities for which the cost impact within a system can be assigned.[6]

Figure 6-3 depicts general cost drivers by CGI visual subsystems. This figure represents an initial effort and is by no means complete with respect to all vendors. It does depict that, perhaps, through extensive interaction with all vendors, an "across-the-board" cost driver table may be generatable, with sub-tables showing vendor unique data.

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[6] Appreciation must go to GE in general, and Mr. P. C. Harris specifically, for their suggestions in developing this subsection.

SYSTEM/SUBSYSTEM	COST DRIVER
CGI Visual System	
- Display Subsystem	• Color VS. Monochrome • FOV (individual display) • Resolution • Number of Displays (Total FOV) • Brightness
- Image Generator Subsystem	• Application (Day/Dusk/Night) • Color VS. Monochrome • Number of objects in scene • Number of moving objects in scene • Resolution • Number of Channels • FOV • Features - Texture - Shading (curved surface) - Environmental effects (weather) - Level of detail management
- Data Base Subsystem	• Size (gaming area) • Scene density

Figure 6-3. CGI Cost Drivers

Again, the table would have to be subject to constant update to remain usable and is dependent upon complete vendor cooperation.

Once the above data is gathered and analyzed concerning CGI unique versus vendor unique data, the impact of these drivers could be considered in light of where the cost impact falls. This data could be displayed in the form of a matrix (Figure 6-4). Again, as with Figure 6-3, this figure is an initial effort intended to be an example of applying the details of data gathered to CGI across-the-board, and, perhaps, supplementing the basic matrix with vendor unique matrices. The completed matrix could be used to predict relative cost impacts. For instance, the greater the number of subsystems affected by a particular requirement, the greater the expected cost impact.

CGI Cost Summary

A point not to be ignored is that PMTRADE must make cost estimations and trade-offs throughout the life of a project. These estimates normally begin in the conceptual phase, and with a Baseline Cost Estimate. Cost estimation is interactive in nature and the accuracy of the estimates is expected to increase significantly through the developmental phases. There are various techniques which could be applicable to CGI costing. However, there are two summary factors inhibiting the use of these techniques. The first is a lack of detailed visual system and subsystem data. The WBS's, a basis for detailed cost information, for simulators normally do not go to the level of detail required to identify CGI visual costs alone. Even if the costs were detailed, their accuracy would be suspect within the total effort since

PERFORMANCE PARAMETER OR CAPABILITY	DISPLAY SUBSYSTEM	IMAGE GENERATION SUBSYSTEM	DATA BASE SUBSYSTEM
Application (D/D/N)	X	X	X
Brightness	X		
Color vs. Monochrome	X	X	
Environmental Effects		X	
FOV (Individual display)	X		
FOV (Total System)	X	X	
Gaming Area			X
Number of Channels	X	X	
Number of Moving Objects in Scene		X	
Number of Objects in Scene		X	X
Resolution	X	X	X
Scene Content (density)		X	X
Shading		X	
Texture		X	

Figure 6-4. CGI Cost/Performance Impact Matrix

there is latitude in the assignment of real costs to work efforts or deliverables. The second consideration is the lack of standard architecture and implementation techniques. One would virtually have to have detailed models with supporting cost data bases for each vendor and each product line.

In summary, it does not seem feasible to develop a single, across-the-board, CGI costing model that would be easily utilized, accurate and maintainable. There are, however, some efforts that could be accomplished. CGI generic cost drivers could, perhaps, be identified and, based on these cost drivers, a form of cost/performance impact matrix developed. These efforts would provide general cost impact information, but would not allocate specific dollars to these performance parameters. The provision of initial and subsequent cost data would be completely vendor dependent. As was seen in Appendix E, which supplemented Section 4, only two vendors provided cost responses to the CGI vendor survey. These two responses were not detailed breakdowns, but macro system cost ranges.

For CGI cost estimation needs, there seems to be no substitute for detailed, indepth, internal knowledge supplemented by the use of experienced resources which are available (i.e., NTEC/ USAF-SIMSPO).

SECTION 7

CONCLUSIONS

This report was prepared in response to PMTRADE's needs for current information on CGI in the following areas:

- Cost/Performance and/or Cost Estimating Models
- The Vanguard of CGI Technology
- A CGI Contact List
- Current Technology
- Anticipated Technology

All of the above areas have been addressed to some extent in the previous sections. The general conclusions of these sections are summarized in the following paragraphs.

Cost/Performance and/or Cost Estimating Models

The development of a usable, easily maintainable, cost-effective costing model for CGI is, by all indications, not feasible at this time. Factors which inhibit the development of such a model are differences in data base techniques, languages, image generation techniques, the implementation of special features (texture, tiling, etc.), hardware architectures and system constraints. The factors are variable not only from vendor to vendor, but within vendor product lines. Where trade-offs are concerned, the variables mentioned above also provide inhibitors. With the possible exception of the displays, subsystem trade-offs are not feasible in today's CGI visual system environment. Trade-offs have to be accomplished at the visual system level

and will be oriented to total system capacity/capability relative to the stated requirement. This generally means do not buy more capacity or capability than is required to accomplish the training requirement. If, in the future, a universal data base language and/or technique evolves, and if architectures become standardized (i.e., through VLSI), costing models will become more attractive and feasible.

There are some near-term efforts that can be considered, in cooperation with the CGI vanguard. For instance, CGI visual subsystem drivers could be determined by vendor. Once this is accomplished, analysis would turn to identifying drivers that are common across the industry. The next iteration would be the preparation of cost impact matrices that provide indications of where costs fall. A third iteration could be the assignment of macro costs. A point to be noted, however, is that any effort of this type would depend on complete vendor cooperation. While most vendors were cooperative in providing information for this study effort, only two vendors supplied any costing data at all.

The Vanguard of CGI Technology

Based on the criteria established in Section 4, this report concludes that the CGI vanguard is General Electric, Evans and Sutherland/Redifon, McDonnell Douglas and Singer-Link. This vanguard is subject to change over the near- to mid-term. Gould, for instance, has announced their GVS-1 visual system which is described in Table E-1. ATS's system may mature and other efforts (Boeing/Ohio State, Cohen's VLSI) are on the horizon.

CGI Contact List

A current listing of those personnel and/or organizations, governmental, academic and industrial, engaged in various CGI visual system efforts provides a valuable tool for obtaining cost/performance data and maintaining touch with current and anticipated technology. Appendix C to this report addresses this conclusion and provides PMTRADE with a list of suggested CGI contacts. Reiterating that this report represents a "snapshot in time" relative to CGI technology, the contact listing will lose its accuracy quickly.

Current Technology

Current technology is impressive and the current product lines offer multi-capable systems with a wide range of options (enhancements) for meeting certain specific needs. There are still some current technology areas, such as helmet mounted displays, textures, FOVs (for certain requirements) and data base generation and management techniques that require improvement. As stated by Cohen in his NTEC "Summary of the CIG Survey" report, the "data base issue is probably one of the sorest issues in the CIG system". Much work is required in the area of a universal language and automated translation method, and the work should revolve around DMA data bases. DMA started data basing the earth in 1959, with complete initial mapping expected around 1990. To attempt to use any other source of information for required gaming areas does not seem cost-effective at all. The DMA/NTEC Project 8742 represents an attempt at beginning to resolve data base problems.

The following three documents represent the best source of current technology information immediately available to PMTRADE. These documents are contained in the CGI technical reference library:

- NASA Ames, "Conceptual Design Study for an Advanced Cab and Visual System," Contract No. NAS2-10464 (Boeing), Preliminary Copy, July 1980.

- NTEC Report, "Summary for the CIG Survey," Technical Report 77-C-0154-1 (USC/ISI), draft, February 1980

- USAF-FDL Report, "CIG Applications Study," Contract F33615-79-C-3600 (LOGICON), draft final, March 1980.

Anticipated Technology

Future technology will, most likely, be incremental in the near-term with quantum leaps occurring in the mid- to long-term. The near-term improvements will be in edge capacities, data base generation techniques, texture, FOV, area of interest displays, and possibly, the utilization of VSLI technology. Boeing, in their ACAVS Study for Ames Research Center stated, "It is Boeing's view that in the mid- to late-1980's simulation of visual systems will turn to pixel-based rather than polygon-based systems." There are ongoing efforts which offer the potential for quantum leaps in edge capacity and scene density such as the Csuri (Computer [illegible] Group) efforts at Ohio State, the Boeing effort, [illegible] technique and the NASA Ames/Army ACAVS project,

if other than today's technology is used. There are numerous sources of current and future technology information available to PMTRADE. Among these are vendors, Government agencies, Government reports and studies, professional conferences and publications. Notable among these are:

- ACM "SIGGRAPH" Conferences
- AIAA "Simulation Technology" Conferences
- "Interservice/Industry Training Equipment" Conferences
- NASA Ames/Army Aeromechanical Labs.
- NTEC (N214, N732, N74)
- SPIE "Simulators and Simulation" Conference
- USAF-SIMSPO
- Vendors

SECTION 8

RECOMMENDATIONS

Attempting to make recommendations based on an effort such as this study provides one with extensive food for thought. An easy way out is to research current, similar efforts and adopt their recommendations on related areas. In part that is what has been done for this report. The recommendations contained in this section will be of two categories: general and specific. General recommendations are those which should be done currently as a normal course of business. Specific recommendations require thought, planning, coordination, implementation time and/or budget actions (which also equal time).

GENERAL

The general recommendations which are discussed here revolve around those efforts which PMTRADE can make to fulfill their requirements for maintaining an awareness of current CGI technology and capabilities, anticipated capabilities and ongoing efforts.

- The results of the current CGI efforts discussed in Section 5 offer an extensive look at current vendors, systems, capabilities, technology and techniques. In addition, some anticipated technology information is offered. These reports (NASA Ames/Boeing, NTEC/USC, USAF-FDL/ Logicon, and updates to the USAF-TAWC

Simulator Comparative Study) should be required reading for those involved in CGI visual system efforts.

- PMTRADE should subscribe to periodicals which cover CGI related topics such as Computer Graphics World and the International Commercial Airlines Organization (ICAO) publication. In addition, the proceedings of conferences and seminars on visual systems should be obtained. Among these are the AIAA Simulation Technology Conference, the ACM SIGGRAPH Conference, the SPIE Simulators and Simulation Conference, and the Interservice/Industry Training Conference.

- The previous recommendation stated that the proceedings of various conferences should be obtained. While this is true, attendance at these events offers even more benefits which include interpersonnel communications and contacts in addition to the material being presented. Therefore, PMTRADE should provide for attendance at selected conferences.

- Liaison with those activities/organizations engaged in CGI visual system efforts should be maintained. The co-located NTEC activities (N-214, N-732, N-74), the USAF-SIMSPO and the Ames Research Center offer extensive, readily available bases of knowledge.

* Liaison with the vendors should be maintained.

SPECIFIC

* PMTRADE should consider recommending timely updates to the JTCG/SATD "Roadmap through CIG Technology". This document has the potential to be a valuable tool in tracking CGI technology efforts. In addition, perhaps it should be expanded to include other valuable efforts such as the NASA Johnson, NASA Langley, Ames Research Center and USAF-FDL/Logicon efforts.

* During the course of this effort, CSC found at least three other Government agencies (Ames, NTEC, USAF-FDL) and possibly four (USAF-TAWC) involved in related CGI efforts. PMTRADE should consider sponsoring a conference of users and/or sponsoring agencies aimed at decomposing unique (user specific) requirements down to a level that would allow the identification of common needs. The development of cost/performance, cost estimating and cost/trade-off models, for instance, may well be a common need. Resources (in terms of dollars) could then be directed towards responding to these common needs in a more cost-effective manner, while individual users could continue efforts on unique requirements.

* There was an opinion among some vendors and users interviewed during the course of this

study that system requirements should be stated in terms of scene and cuing needs versus system capacities (edges, scan lines, etc.). There is still a long way to go in being able to accomplish this goal; however, there are ongoing efforts towards this end. The USAF Integrated Cuing Requirements Study and the efforts by Mr. J. Sinacori for Ames Research Center are two examples. PMTRADE may give consideration to joining some of these efforts. For instance, the Cuing Requirements Study may become a joint effort next year.

- Standardization of, automation of, and better management of CGI data bases are efforts that will make visual systems more useful and responsive to users needs. PMTRADE should give consideration to initiating new or joining ongoing efforts in these areas. There are ongoing efforts such as the DMA/NTEC universal data base effort that may benefit from multiservice interest and funds.

- In the area of cost/performance, PMTRADE should consider an effort towards parameterizing industry common cost drivers and developing cost impact matrices. The CGI vendors would have to be brought into this effort and would have to be completely cooperative for any assurance of success. The Interservice/Industry Conference in Utah

may be the platform for discussing this, initially, with the vendors. Prior multi-user coordination, with respect to the pooling of common ideas, may be very useful.

- Finally, with the entry into production of the XM1 COFT, PMTRADE will probably be managing the single largest buy of CGI based simulators to occur. This opportunity should be used to gather data which, when future cost model efforts are considered, may well provide the basis for information on production learning curves, economies of scale effects, analogy data needs, rules of thumb costing and/or CER development.

APPENDIX A

GLOSSARY

OF ABBREVIATIONS, ACRONYMS AND TERMS

A/A	Air-to-Air
*Accommodation (visual)	Specifically, the dioptric adjustment of the eye to attain maximal sharpness of the retinal image for an object of regard. Focusing of the eye.
ACM	Air Combat Maneuvering
ACS	Air Combat Simulator
*Active TV Lines	The number of lines actually scanned on the photosensitive element of the camera or the CRT phosphor in a single frame, in distinction to the total number of scan periods per frame, including those needed for vertical retrace.
Acuity	See resolution and visual acuity.
Adage	A computer system with graphics display capability that is used as an interface between the instructor console and the simulator central processing units.
*Adaptation (to light or dark)	The adjustment, occurring under changes in illumination, in which the sensitivity to light (or light threshold) is increased or reduced.
*Aerial Image Displays	An image, especially a real image, formed by an optical system but perceived by alignment of the viewing eye with the path of light emerging from the optical system, instead of being focused first as an image on a receiving screen. Typical aerial image displays are the microscope, or a CRT viewed in a curved mirror.
AFHRL	Air Force Human Resources Laboratory

*Aliasing	In communications theory, the generation of spurious signals caused by sampling a signal at a rate lower than twice its frequency. In a CIG scene, sampling refers to the spatial frequencies involved in both the computation of the scene and its display. The result is spatial and/or temporal image defects. Manifestations of aliasing include edge stair-step, scintillation of small scene surfaces, breakup of long narrow surfaces, positional or angular motion of edges in discrete jumps or steps, moire in regions where there is periodic structure, double imaging, and loss of dynamic image integrity due to field tracking induced by edge motion perpendicular to the scanning direction.
*Anti-aliasing	Image processing techniques, usually involving low pass filtering, that reduce spatial and/or temporal aliasing phenomena. To avoid significant reduction in image resolution, it is generally necessary to perform the anti-aliasing on an image with higher resolution than the one to be displayed.
AOI	Area of Interest. Part of the visual display that contains a high-resolution terrain video presentation. The remainder of the display can be low-resolution supporting information such as featureless sky/earth or sky/checkerboard patterns.
Arc Minute	A measure of resolution as applied to human perception or acuity. One (1) minute of arc is equal to 1/3000th of the distance to an object or 12 inches at 3000 feet.
Artifacts	With respect to CGI systems, artifacts are those phenomena which are encountered in the engineering, operation and use of CGI visuals such as aliasing, flicker and the "jumping" changes involved in dynamically changing the level of detail.
A/S	Air-to-Surface

ASD	U.S. Air Force Aeronautical Systems Division (Wright-Patterson AFB, OH.)
*Aspect Ratio of a Raster	The ratio of the frame width to the frame height.
ASPT	Advanced Simulator for Pilot Training (Williams AFB, AZ.)
ATD	Aircrew Training Device
BAC	British Aerospace Corporation
** Back Edge	A Back Edge is one that cannot appear in the environment being rendered because it lies on the side of an object away from the observer.
**Back Face	A "back face" is a face that cannot appear in the picture by virtue of being on the side of an object away from the observer.
Bicubic Patch	A technique utilized for the generation of curved surface images. The Bicubic Patch method generates a curved object through third-order surface patches.
*Binocular	1. Pertaining to both eyes. 2. The use of both eyes simultaneously in such a manner that each retinal image contributes to the final image.
*Brightness	The subjective attribute of any light sensation giving rise to the perception of luminous intensity, including the whole scale of qualities of being bright, light, brilliant, dim, or dark. More popularly, brightness implies the higher intensities, dimness the lower. At one time the term brightness was also used for the quantity luminance; this usage is no longer correct.
Calligraphic	The electronic technique of random writing or painting of a display versus the raster scan process.

*Candela	The unit of luminous intensity in the CIE photometric system. It is 1/60 of the luminous intensity of 1 cm^2 of a blackbody radiator at the temperature of solidification of platinum. The term is intended by the CIE to be used in place of candle, international candle, and new candle.
*Cathode Ray Tube (CRT)	A tube in which the electrons emitted by a heated cathode are focused into a beam and directed toward a phosphor-coated surface that becomes luminescent at the point where the electron beam strikes it.
CCTV	Closed Circuit Television
CDIG	Calligraphic Digital Image Generation, a Singer Trademark. Also referred to as DIGS.
CGI	Computer Generated Imagery
CIG	Computer Image Generation
*CFF (critical flicker frequency, critical fusion frequency, critical frequency for fusion)	The rate of presentation of intermittent, alternate, or discontinuous photic stimuli that just gives rise to a fully uniform and continuous sensation obliterating the flicker.
Chromaticity	The categorization of color into hues.
*Chromaticity Coordinates	The ratios of each of the tristimulus values to the sum of the three. Symbols: x, y, and z.
*Chromaticity Diagram	A plane diagram formed by plotting two of the three chromaticity coordinates against one another, thus constituting a graphical representation of stimulus characteristics derived from color mixture data.
Clipping (Also see scissoring)	A process which, when the total line length of an edge extends beyond the viewing area of a display, calculates new vertices points and only that portion of an edge visible is drawn.

**Cluster	A cluster is a collection of faces that can be treated as a group for some special reason.
Collimate	1. To render a bundle of rays parallel. 2. To adjust an optical instrument so that is mechanical and optical axes are coincident or parallel.
*Color	1. A sensory or perceptual component of visual experience, characterized by the attributes of hue, brightness, and saturation, and usually arising from, or in response to, stimulation of the retina by radiation of wavelengths between about 380 and 760nm. Sensory component, such as white, gray, and black, which have neither hue nor saturation are properly, but are not always, included with colors. Variously synonymous with hue, tint, or shade. 2. A stimulus or a visual object which evokes a chromatic response.
**Color or Shading Rule	This algorithm relates the appearance of a face in its visible location.
COMPU-SCENE	A General Electric trade name for a daylight CGI system.
Computer Generated Imagery (CGI)	The images produced by means of computer image generation.
*Computer Image Generation (CIG)	The technology or techniques, for generating real-time pictures of a visual operating environment by digital processing of model data.
COMPUTROL	ATS trademark for a full color day/dusk/night CGI visual system.
*Contrast	1. The difference in brightness between two areas. 2. Any one of several ways of mathematically expressing the difference in luminance of two areas.

*Contrast Threshold	The contrast associated with the minimum luminance difference between two areas which can be perceived as having different brightnesses.
**Contour Edge	A Contour Edge is an edge that forms part of the outline of an object as seen by the observer.
*Convergence Angle (eye)	The angle between the two visual axes.
*Convergence Angle (in color CRT's)	The angle at which electron beams from separate color guns of a color CRT display come together at the phosphor.
*Cornea	The transparent anterior (front) portion of the fibrous coat of the eye.
CPU	Central Processing Unit
Crawling (see scintillation)	
*Critical Flicker Frequency (See CFF)	
*Critical Fusion Frequency (See CFF)	
CRT (See Cathode Ray Tube)	
*Data Base	1. A numerical representation of the visual scene that can be viewed in real-time with the CIG visual system. Data base conventions vary between reference to the total three dimensional scene available over the gaming area and reference to just that scenery actually visible in display FOV under specific viewing conditions. 2. In a simulator there will be a total data base representing the full gaming area required for the simulator (i.e., 600nm x 600nm), that will reside in some form of mass storage, probably disk. There will also be an "Active Data Base" which will reside in fast memory and represents the area immediately available to the operator (his immediate FOV).

DIG	Digital Image Generation
*Display	The physical device that forms an image for trainee viewing in an ATD. Two typical ATD displays are a CRT with optics to place the image near optical infinity, and a front or rear projection screen combined with a television projector.
*Display Field	The field of view, measured in terms of visual angle, as defined by the edges or limits of an image display.
DMS	Differential Manuevering Simulator (NASA, Langley AFB, VA.)
DOF	Degrees of Freedom
Double Interlaced Scanning (Interlacing)	The system of scanning alternate scan lines (odd lines first and even lines second). Each set of lines becomes a field which, when displayed, are superimposed to create a frame or complete picture. Used to reduce the problem of Flicker.
DRLMS	Digital Radar Land Mass System
Duoview	A Redifon trademark for a double-channel visual system.
DVST	Direct View Storage Tube (See Storage Tube)
*Dynamic Visual Acuity	Visual acuity measured with a moving target.
*Edge	In CIG, an edge is a straight or (rarely) curved line segment defined by two vertices of a polygon. Scene edges represent boundaries in the scene where either the shape, color, or brightness of scene detail changes. Consequently, natural fields, mountains, buildings, and so on are shaped and distinguished by edges of polygons.

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**Edge Intersection	Edge intersection has to do with calculating the visibility of an edge. A calculation is made whenever two edges intersect to determine which edge is in front of the other.
**Environmental Coordinate System	The total coordinate system used to relate all objects to the viewer. All objects would be transformed to this system to determine their placement and their visibility.
**Eye Coordinate System	The coordinate system relating the position of the eye and its viewing direction.
Eyepoint	In a CIG ATD, the eyepoint is the simulated single point location of the observer's eye relative to a monocular scene presentation.
Face	An object drawn on a display and formed by a series of edges. (**) A polygon, usually planar, bounded by straight lines and formed by a series of edges.
FDL	U.S. Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH.
Fidelity	A measure of the degree to which a simulator simulates the intended system.
*Field (in CRT displays)	One of the equal parts into which a television frame is divided in an interlaced system of scanning. One vertical scan, containing many horizontal scanning lines, is generally termed a field. Consists of the odd or even raster lines.
*Field-of-View (FOV)	The horizontal and vertical subtended angles from the eyepoint.
Fixation Point	The point in space to which one or both eyes are consciously directed. In normal vision its image is on the fovea.

*Flicker	Perceptible temporal variation in luminance.
Foot Lambert	A unit of luminance that measures light energy emitted or reflected from a surface in terms of lumens per square foot.
*Fovea	A small pit in the center of the retina in which the density of photoreceptors is greater and which controls perception of fine detail.
*Foveal Vision	Vision achieved by looking directly at objects so that the image falls on or near the fovea.
Fractal	A texturing method based on the mathematical properties of natural forms.
*Frame (CRT)	One complete scan of the image area by the electron beam. A frame consists of two interlaced fields, or all of the visible scan lines. Also called a raster.
Frame Rate (CRT)	The number of frames produced per second; expressed in Hertz (Hz). Also called the frame frequency or picture frequency. In the U.S. it is 30/second while in England it is 25/second.
*Gamut (color)	The range of colors that can be obtained with a particular set of primaries or materials.
*Glossiness (as a dimension of color)	An attribute of the appearance of a surface dependent upon the type and the amount of reflection. Low glossiness is characteristic of rough diffusing surfaces and high glossiness of smooth surfaces that give a shiny or lustrous effect.
*Gray	A color that is achromatic, or without hue, and which ranges from white to black.

*Gray Scale	A series of achromatic tones having varying proportions of white and black to give a full range of grays between white and black. These are usually regularly spaced with regard to reflectance or transmittance, and can be in either linear or log steps.
*High Order (CRT interlace system)	An interlace system in which more than two fields are employed; e.g., 3:1, 4:1 interlace.
*Horizontal Resolution (CRT)	The number of individual picture elements that can be distinguished in a horizontal scanning line within a distance equal to the picture height.
HRL	U.S. Air Force Human Resources Laboratory, Williams AFB, AZ.
*Hue	The attribute of color sensation ordinarily correlated with wavelength or combinations of wavelengths of the visual stimulus and distinguished from the attributes brightness and saturation. Comparable to "blue," "green," "yellow," etc.
*Insert	The replacement of a portion of the scene by another scene, usually of higher resolution.
*Interlace (CRT)	A scanning process in which the distance from center to center of successively scanned lines is two or more times the nominal line width, and in which the intervening lines are scanned during subsequent fields. See double interlaced scanning.
**Implied Edge	The edge generated at the intersection of two faces.
LAMARS	Large-Amplitude Multimode Aerospace Research Simulator. (Wright-Patterson Air Force Base, Ohio)
LAMBS	Large-Amplitude Motion Base Simulator. (Vought Aeronautics Company, Dallas, TX)

LAS/WAVS	Large-Amplitude System/Wide-Angle Visual Simulator. (Northrup Corporation, Hawthorne, CA)
*Lateral Alignment	The convergence angle or angle between the visual axes, necessary for the display user to fixate on corresponding points in the two images.
**Linearly Separable	Two clusters are linearly separable if a plane can be passed between them.
*Line Frequency (TV)	The number of times per second that a fixed vertical line in the picture is crossed in one direction by the scanning spot. Scanning during vertical return intervals is counted.
*Line Number (TV)	1. The total number of line scan periods per TV frame. Not all of these periods are used to scan the image (in the camera) or the phosphor (in the CRT), a portion are used in vertical retrace. 2. The sequential numbering of the active TV lines on the sensor or phosphor surface.
LLLTV	Low Light Level Television
MACS	Manned Air Combat Simulator. (McDonnell Douglas Corporation, St. Louis, MO.)
MBS	Motion Base Simulator. (McDonnell Douglas Corporation, St. Louis, MO.)
*Mesopic	Pertaining to vision at a luminance range in which both rods and cones function.
*Metameric Colors	Colors of different spectrophotometric composition which appear the same under given conditions. Appearance is often defined in terms of chromaticity.

**Minimax Test	These tests allow for a quick rejection of objects that do not obscure one another. It involves testing the maximum values in x and y of one face as it relates to the minimum x and y of another face.
*Model Board	A scale-model of a ground area or an aircraft, viewed with a servo-mounted television camera and used to provide a visual scene.
*Modulation	Mathematically, the absolute value of the difference between two quantities, such as voltage or luminance at two times or at two locations, divided by their sum. Strictly speaking the variation in the value of the quantity should be sinusoidal, in which case the maximum and minimum value are used to calculate modulation. Modulation is one of several ways of expressing luminance contrast.
*Modulation Sensitivity	A statement of ability to distinguish differences in luminance, with these luminance differences expressed as modulation.
*Modulation Transfer Function (MTF)	The curve or the mathematical expression describing the curve generated by a series of modulation transfer factors taken over a range of frequencies; usually from a frequency of zero to the frequency at which the modulation transfer factor drops to zero.
*Monocular	1. Pertaining to or affecting one eye. 2. Pertaining to any optical instrument which is used with only one eye.
*MTF (See Modulation Transfer Function)	
*Munsell Color System	A series of about one thousand standard color samples, each designated by a letter-number system. The series represents various combinations of hue, saturation, and brightness and includes

	variations of brightness of the achromatic colors which have neither hue nor saturation.
NASA	National Aeronautics and Space Administration
**Non-planar	A face that does not totally reside in a plane.
Novoview	An Evans and Sutherland trade name for a night/dusk/dawn CGI visual system.
NVS	Night Visual System
**Object Coordinate System	The object coordinate system relates the surfaces of a particular object to one coordinate system. This allows the object to be repeated and/or moved very easily.
*Occultation	The visual obstruction of scene lights and/or surfaces by other surfaces. Also referred to as interposition.
*Octave	The interval between two frequencies having a ratio of 2:1.
OFT	Operational Flight Trainer
*Overlay	The adding of an image of a small object such as an aircraft over a larger generally homogeneous scene such as sky.
*Overload	The condition in which the processing capacity of a CIG system is exceeded due to high scene complexity encountered under given viewing conditions.
**Penetration	The intersection of any two faces that exists in an environment.
*Periphery (Visual Field)	Noncentral portions of the field.
**Perspective Transformation	The transformation that produces the illusion of depth on a flat screen of the environment.

*Phosphor Persistence	The length of time required after the removal of excitation for the luminance of an excited phosphor to drop to 10 percent of its peak value.
*Photopic	Pertaining to vision at a sufficiently high luminance that cone receptors are involved. An opposite meaning word is scotopic, for night seeing.
Picture Element	1. The smallest detail distinguishable in a scanning line. (In color TV it's a dot.) 2. The smallest section of a picture area resolved by scanning. Calculated as aN^2 where a=aspect ratio and N= number of lines.
Picture Frequency (See Frame Rate)	
Pixel	Contraction of picture element.
Planar	1. A point on a surface at which the curvature is zero. 2. Flat surfaces. 3. ** When the plane of the face and the face coordinate triples match, the face is said to be planar.
Plane	A flat level or even surface. ** A surface of such nature that a straight line joining any two of its points lies wholly in the surface.
**Plane Equation	The equation used to define the location and orientation of the plane of the face.
Plasma Display	A flat panel neon-based gas discharge display system. Capable of character display or line drawing through the activation of spots by voltage applied via x and y electrodes.
Polygon	A closed plane figure or object usually containing more than four sides and angles.

*Purity (Color) — A measure of the degree of freedom of a color from achromatic content; or, the degree to which a color approaches the condition required for maximum saturation.

Quantization Effects (See Aliasing)

*Radian — The angle subtended by an arc of a circle equal in length to the radius of the circle. One radian is equal to 57.3 degrees.

*Raster (CRT) — A predetermined pattern of scanning lines that provides substantially uniform coverage of an area or display.

Raster Frequency (See Scan Rate)

Raster Line (See Scan Line)

*Raster Luminance (CRT) — The luminance of an extended area on the face of the CRT.

*Real Image — An optical image that can be received on a screen; one formed by the meeting of converging rays of light.

*Recognition — In target acquisition, the assignment of an object (as seen on a display) to a class of objects: e.g., tank.

*Recognition Latency — The period of time elapsing between the first appearance of a target in display and a response by the observer indicating he has located and recognized it.

*Refresh Rate — The frequency with which the electron beam of a CRT display returns to a given phosphor spot. Nominally assumed equal to the frame rate, however, it is related to the persistence of the phosphor being used in the CRT.

*Resolution (TV)	1. A measure of ability to delineate picture detail. Resolution in cathode ray tubes is usually expressed as the number of scan lines in the vertical dimension of the raster (i.e., the direction perpendicular to the scan lines). A line of TV resolution is either the light or dark portion of a periodic target, as opposed to the designation of resolution as the number of line pairs (both the light and dark portions of a periodic target) used in optics. Two lines of TV resolution are required to equal one line pair of optical resolution. 2. The degree to which the detail of a displayed scene can be discriminated by a human, expressed in arc minutes. Also called acuity or visual acuity.
*Response Latency	The lapse of time between the presentation of the stimulus and the occurrence of the response.
*Resting Position (of accommodation)	The refractive state of the eye when there is no stimulus to focus at any given distance. Traditionally spoken of as being zero diopter (accommodation to infinity), it is now more often placed nearer at about 0.5 to 2 diopters (2 to 0.5 meters); this is presumed to be the basis for night or empty field myopia.
*Retina	The portion of the eye which contains the photoreceptors.
*Reliability	The coefficient of correlation obtained from two applications of the same test. (Properly, the coefficient of reliability.)
*Retrace (in CRT's)	Return of the beam on the cathode ray tube to its starting point after the completion of a line or a field; also that portion of the sweep waveform that returns the spot to its starting point.

SAAC	Simulator for Air-to-Air Combat. (Luke AFB, AZ.)
*Scan Line (TV Camera and CRT)	A single continuous narrow strip that is determined by the process of scanning. (The process of directing a beam of energy successively over the elements of a given region; e.g. a CRT tube.)
Scanning	The process of analyzing the light values of a scene, to be displayed, into picture elements or Pixels to produce a succession of signal pulses which vary in amplitude with light intensity. In this sequential system of scanning, a concentrated beam of electrons moves in a succession of parallel straight lines across a display.
Scan Rate (Raster Frequency)	Number of scan lines (raster lines) painted or displayed per second. In the U.S. it is 15,750 (30 frames x 525 lines).
*Scene	The approximation of a real world visual environment the observer sees at any given moment while looking through the available aircraft windows on the simulator.
**Scene Coordinate System	The coordinate system that relates the viewer's scene presentation to the viewer.
Scintillation	An aliasing effect. Occurs as a flickering or shimmering when an item required to be displayed is smaller than a Pixel.
Scissoring (also see Clipping)	A process where the portions of an edge that extend beyond the viewing area of a display are blanked out so that only the portion visible on the screen is written.
*Scotopic	Pertaining to vision at relatively low luminance so that only rod receptors are involved.

*Screen Display	An image display in which the optical element closest to the eye is a diffusing surface or screen on which the image is formed. Also see aerial image display.
**Segment Comparisons	Segment comparisons are performed in the x-z plane. The segments are defined by the number of edge intersections. In each segment a search is made of all visible edges to determine the closest to the viewer and the rest are eliminated.
*Small Field Tritanopia	A normal reduction color discrimination for blue wavelengths for small color fields (nominally smaller than 20 arc minutes), with the result that all colors can be matched by a mixture of two primaries, and purplish blues and greenish yellows are confused with neutral and with each other.
SMS	Shuttle Mission Simulator. (NASA Johnson, Houston, TX.)
*Snellen Visual Acuity	Measured by the ability to correctly read a standard set of letters of graduated size. Expressed as a comparison of the distance at which a given set of letters were correctly read to the distance at which the letters would be read by someone with clinically normal eyesight. A value of 20/80 indicates that an individual read at 20 feet the letters normally read at 80 feet.
**Sorting	Sorting is an operation that orders a set of records according to a selected key.
*Sound Level (SL)	A measure of the overall loudness of sounds based on approximations of equal loudness of pure tones. It is a weighted measure, expressed in decibels, obtained by the use of a meter with specific weightings across the sound frequency spectrum.

*Sound Pressure (SP)	The extent of the variation in atmospheric pressure produced by a sound wave. Measured in newtons/square meter (N/m^2) and normally used to mean the effective root-mean-square sound pressure.
*Sound Pressure Level (SPL)	The root-mean-square sound pressure expressed in decibels relative to a standard reference pressure (normally $2x10^5$ N/m^2).
*Spatial Acuity	A general term referring to the visual ability to discriminate between targets on the basis of their relationships in space.
*Spatial Distribution	Allocation or apportionment of a quantity throughout a linear, areal or spatial extent, such as cycles per millimeter or candelas per square meter. In distinction to temporal distribution, which is the apportionment of a quantity over a time period, such as cycles per second (Hz).
*Spatial Frequency	A measure of the number of cycles in a grating or target of alternating light and dark bars as a function of their linear extent. Normally measured in terms of cycles/millimeter or cycles/degree of visual angle. Used in distinction to temporal frequency (usually designated simply frequency) which is expressed in units such as cycles per second (Hz).
SP-1, SP-2	Special Performance 1 and 2. (Evans and Sutherland visual systems)
*Staircasing (Stairstepping)	The appearance of a smooth diagonal as a staircase due to aliasing during image generation or because of a display raster.
*Stereo Acuity	The ability to perceive depth by the faculty of stereopsis, represented as a function of the threshold of stereopsis.

*Stereopsis	1. Binocular visual perception of three-dimensional space based on retinal lateral disparity. 2. Visual perception of depth or three-dimensional space.
Storage Tube	A CRT with special construction which allows for a single writing on the display without refresh. A major disadvantage of the storage tube is that it cannot be selectively erased but must be erased entirely.
*Surface	A typically opaque bounded area in a CIG scene forming a part of the runway, landmass, building, and the like.
**Surface Normal/ Face Normal	A surface normal is an outward-pointing vector, normal to the surface of the object.
**Surrounding Polygons	The surrounding Polygon is a test used to determine if a polygon obscures a point or not.
TAWC	U.S. Air Force Tactical Air Warfare Center. Eglin AFB, FL.
Texture	An irregularly painted or covered surface used to give character to an object or scene.
*Three-dimensional Color Space (for CRT's)	A three-dimensional space defined by the amount of each of the three primary colors (red, blue, green) present on the display.
*Threshold	The statistically determined point on the stimulus scale at which occurs a transition in a series of sensations or judgements.
*Threshold Contrast (See Contrast Threshold)	
Tiling	A process used to overlay an object or scene with a regularly shaped pattern such as adding a brick pattern to a wall.

**Transformation	The act of rotating or mapping one configuration into another in accordance with some function.
Translucent	Partially transparent. Translucent objects are those through which other objects can be seen, but not with complete clarity. Items such as fog, smoke, clouds, etc.
*Transparency (as dimension of color)	Attribute of appearance that permits perception of object or space through or beyond a surface.
Transport Delay	In an interactive real-time simulator this is the delay encountered between the time when a physical action is taken (movement of a joystick) and the subsequent reaction to that action is seen on the display.
*Triad (in color CRT's)	A grouping of three colored phosphor dots (red-, blue- and green-emitting) on the face of a CRT.
*Tri-bar Test Target	A target consisting of three equal-sized bars of defined length and width. Spacing between the bars is usually equal to bar width.
*Trichromatism	Color vision in which mixtures of three independently adjustable primaries (e.g., red, gree, and blue) are required to match all perceived hues.
*TV Line Number	The number of scan periods per complete image scan (525 for U.S. commercial broadcast TV). The actual number of lines scanned on the camera image or CRT phosphor surface are less than the number of scan periods because of vertical retrace requirements. The lines actually scanned are referred to as the active lines.
**Use of Plane Equations	The plane equation is used for many things in hidden surface removal. By substituting the values of another plane the relationship to the original

	plane may be established. The z values can be arrived at and provide distance to the viewer and the face normal may be calculated for back face removal.
VACS	Vought Air Combat Simulator. (Vought, Dallax, TX.)
Vector	A line whose length is proportional to the magnitude of the quantity, and whose direction is that of the vector. Typical vectors are force velocity and electrical field intensity.
*Vergence	1. The angular relationship between the rays of light from a single object point. Usually expressed in diopters (1/apparent distance, in meters, to the source of the light rays). 2. In some sources, the angle between the visual axes of the two eyes.
*Vernier Acuity	Visual acuity based on the ability to detect the alignment or the non-alignment of two lines, as in the reading of a vernier scale.
*Vertical Resolution	1. The number of active TV lines in a horizontal scan system. 2. The number of distinct horizontal lines, alternately black and white, that can be seen in the CRT image of a television test pattern; it is primarily fixed by the number of horizontal lines used in scanning and by the Kell factor.
Vertices	The end points, or maximum extension of straight lines (edges) drawn on a display.
*Visual Acuity	1. Ability to resolve or separate detail in a small high contrast target. 2. A unit equal to the reciprocal of the smallest resolvable target detail in arc minutes.

*Visual Angle	The angle subtended by the extremities of an object at the entrance pupil or other point of reference of the eye.
*Visual Field	The area or extent of physical space visible to an eye in a given position.
VITAL	Virtual Image Takeoff and Landing. A McDonnell-Douglas trademark for a calligraphic visual system.

* From HRL Interim Report on Integrated Cueing Requirements for Aircrew Training Devices, Contract No. F33615-79-C-0014, June 1980.

** From Glossary, FDL Computer Image Generation Applications Study, March 1980.

ATTACHMENT 1

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APPENDIX A

The following information was extracted from Section II of the U.S. Army Electronics Command Pamphlet ECOMP 11-4, Volume 7, Cost Estimating Guide. It is provided to supplement the reader's knowledge of costing.

1. Cost Categories.

Cost Categories are defined in AR 11-18 and their interpretation as applied to electronic systems/equipment are delineated throughout this pamphlet as required. The key cost analysis definitions used in all studies are listed below:

a. Flyaway Cost: Total Army procurement appropriations (APA), expenditures of the Investment Recurring and Nonrecurring cost categories for the production of the Primary and Secondary Mission Equipment of the work breakdown structure. This term is also known as Rollaway or Sailaway depending on the commodity.

b. Weapon System Cost: Flyaway Cost plus those costs necessary to deploy a weapon system. These are Investment Recurring and Nonrecurring PEMA costs for elements of Training, Peculiar Support Equipment, System Test and Evaluation, System/Project Management, Data, Industrial Facilities, Operation/Site Activation, and Common Support Equipment.

c. Procurement Cost: Weapon System Cost plus the Investment Recurring and Nonrecurring PEMA costs for Initial Spares and Repair Parts.

d. Program Acquisition Cost: Procurement Cost plus research, development, test and evaluation (RDTE) and Military Construction, Army (MCA) expenditures associated with the Development, and Invest-

ment Recurring and Nonrecurring cost categories for the entire work breakdown structure.

e. Hardware Cost: Total expenditures (all appropriations) necessary to produce the Primary and Secondary Mission Equipment for the Investment Recurring cost category.

f. Production Cost: Hardware Cost plus the total expenditures (all appropriations) for the Investment Nonrecurring cost categories for the Primary and Secondary Mission Equipment.

g. Program Cost: Total appropriations for the entire work breakdown structure for the Development and Investment Recurring and Investment Nonrecurring cost categories.

h. Life Cycle Cost: Total appropriations for the entire work breakdown structure for all cost categories.

2. Other Cost Related Terms:

a. Cost Factor: A cost per unit of resources (e.g., $/gal), hence, a value established on a per-unit basis which, when multiplied by the number of units or program factor yields the estimated cost.

b. Cost Estimating Relationship (CER): A fundamental expression which states that the cost of something may be estimated on the basis of a certain variable or set of variables. The relationship is derived by analyzing historical data on different systems to obtain a functional relationship between system characteristics and cost. The variable to be estimated will be called the dependent variable, and the variable to which the dependent variable is related by the CER will be called the independent variable. A CER in which the cost is directly proportional to a single independent variable is called a cost factor.

c. Cost Model: A mathematical expression or algorithm used to combine a predetermined set of cost elements, cost factors, and

CERs for the derivation of totals and subtotals of a complete cost estimate.

d. Cost Uncertainty: In all cases of projected cost estimates, some degree of uncertainty will exist and it is therefore advisable to state projected cost estimates in terms of most likely value, lowest value, and most pessimistic (highest) value. The most likely value would be that value normally used in budgeting and programing. A guidance paper prepared by the Office of the Comptroller, ECOM, was distributed throughout the command on 29 December 1971, entitled "Uncertainty Analysis in USAECOM Cost Studies".

e. Baseline Cost Estimate (BCE): The first deliberate, complete cost estimate made for a new major system acquisition start, normally performed prior to (and for the purpose of) ASARC/DSARC I. This estimate addresses the costs of acquisition plus ownership (operating) in work breakdown structure (WBS) terms (usually to the summary level); and specifies desired unit costs for use as cost parameters and "design-to" unit production cost goals.

f. Independent Parametric Cost Estimate (IPCE): An estimate prepared independently by Comptroller organizations, using parametric techniques. This estimate is used as a test or check of either the baseline or current estimate submitted by the proponent at ASARC/DSARC decision points. IPCEs are also prepared for systems under Selected Acquisition Report (SAR) procedures for inclusion in that document.

g. Required Operational Capability (ROC) (Formerly MN) Estimate: A broad-based, summary type estimate made for inclusion in the ROC document. This estimate will be confined to acquisition costs only with procurement (or investment costs) included only when a defined end product is specified in the ROC.

h. Design to Unit Production Cost (DTUPC): That cost established prior to development of an item to guide the design of the item so that it can be produced, based on a stated level of production at or below that cost. The concept requires that an item be designed at an optimum balance of cost and essential

performance characteristics. It does not contemplate "all the performance we can buy at the established cost". It requires trading off performance, cost and schedule to achieve the optimum balance of the factors.

i. Cost Track: A historical record of weapon system estimates developed by recording cost estimates as they occur. An integral part of this record consists of comparing validated successive estimates to identify changes and to determine and document reasons for change.

j. Cost Estimating by Analogy: Analogy is commonly defined as an agreement, likeness, or correspondence between relations of tings to one another; a partial similarity in particular circumstances on which a comparison may be based. The comparison process is to take note of the differences and similarities of the items being compared. In cost estimating, the analogy can be based on the likeness or correspondence of technical, physical, and/or functional attributes. Noting these similarities to items of known cost, a basic estimate can be made and then adjusted to provide for the cost effects of the di-ferences between the items.

k. Cost Estimating by Industrial Engineering: This method of cost estimating examines the cost of material, labor, and overhead for the individual piece parts that make up a system. The industrial engineering approach can be used when the item design is pretty well known or established. Also, it can be used in reinforcing portions of the analogy approach. It is especially useful when a hardware model (6.2 or 6.3) is available and the basic component makeup exists. The greatest difficulty in applying this approach is that the Government is not the producer, and therefore, does not have exact knowledge or control of the manufacturing/fabrication process or subcontracting criteria (make or buy). Not having this knowledge, the estimator is left with the ability to roughly price out the material costs. He cannot, however, estimate with any degree of accuracy, direct labor or overhead costs, since these are dependent upon the manufacturing process and accounting procedures for individual firms. The estimator

does not have a prior knowledge of this information. For estimating purposes, however, it might be possible to develop general factors that lump direct labor, burden, and profit together and this factor might then be applied to the material cost estimate.

l. Statistical Methods: The use of statistical methods is an important feature of cost analysis. Data on past, current, and future systems frequently must be analyzed statistically to determine relationships between costs and system characteristics. The objective of such analysis is to develop generalized cost estimating relationships suitable for application to future systems and force proposals. Statistical methods are especially important in the early phases of a system's costing. As the system develops and its physical specifications become better defined, more direct methods of estimating the costs of material, labor, and engineering associated with the system can be substituted for the generalized cost estimating relationships.

m. Cost Sensitivity Analysis: This is a technique employed within the context of both individual system and force structure cost analysis. For the former, it involves the systematic examination of the effects of changes in total force structure cost resulting from variations in characteristics, size, and composition (mix) of the force.

n. Constant Year Dollars: The phrase "constant dollars" is always associated with a base year (e.g., FY 73 constant dollars). An estimate is said to be in constant dollars if costs are adjusted so that they reflect the level of prices of the base year. When prior or future costs are stated in constant dollars, the figures given are adjusted to presume that the "buying power" of the dollar was the same and will continue to remain the same as in the base year.

o. Current Year Dollars: Current year dollars are current to the year the work is performed. When prior costs are stated in current year dollars, the figures given are the actual amounts paid out. When future costs are stated in current year dollars, the

figures given are the actual amounts which will be paid, including any amount due to future price changes. When making future estimates, it is necessary to initially assume a base buying power for each dollar (constant year) and then apply an escalating factor for inflation which converts the estimate into current year dollars. The "current year" in "current year dollars" does not refer to the year in which the estimate is made or any other single year.

APPENDIX B

CGI SURVEY DATA ELEMENTS

During the conduct of this study, CSC contacted via telephone, and/or addressed survey letters to 18 vendors and/or integrators, and eight Government agencies. These efforts were supplemented by visits to selected locations. The letters to vendors addressed specific items which CSC felt they could contribute and each letter contained the attachment shown in this appendix. A similar effort was directed towards the Government agencies.

ATTACHMENT

Computer Sciences Corporation (CSC) under Naval Training Equipment Center (NTEC) contract N61339-79-D-0008, Delivery Order No. 5, is performing a Computer Generated Image (CGI) current technology assessment and cost/performance model feasibility study. This study is being performed for the U.S. Army Project Manager for Training Devices (PMTRADE). PMTRADE is a major purchaser of training simulators used for Army flight and ground simulation requirements.

This study is addressing the entire CGI visual system by it's functional subsystems (data base, image generation and display), and has two objectives. The first objective is to data base the technology of CGI with emphasis on present capabilities, technological constraints, cost intensive features/factors and anticipated capabilities. The second objective is to determine the feasibility of developing a CGI cost/performance model for use by PMTRADE personnel. In addition, CSC expects to receive various discussions from vendors concerning new or needed techniques, studies or research efforts involving all aspects of the CGI arena. These discussions will be included in the final report.

In fulfilling the requirements of this effort, CSC had anticipated visits to CGI and simulator vendors during August 1980, however, telephonic and mail contacts may provide the necessary information. Listed below are the data elements about which CSC would appreciate technical information with respect to your CGI/simulator/trainer products. If you have published literature which contains the required technical information, a copy of this literature would suffice. The information provided by your company will be

used solely as input to the final report provided to PMTRADE. Any data which you indicate as sensitive or proprietary will be so treated.

The primary items of interest are:

1. Data Base:
   a. Structure
      (1) Structure
      (2) Capacity
      (3) Access Time
   b. Languages
      (1) HOL
      (2) Special Purpose
   c. Generation Techniques
      (1) Manual
      (2) Interactive
      (3) Automated
   d. Special Features
   e. Technological Constraints
   f. Cost Intensive Factors/Features
   g. Performance Parameterization Measures

2. Display Terminal/System:
   a. Category
      Dumb (Slave)/Smart/Intelligent (Stand-Alone)
   b. Type
      Raster/Calligraphic/Plasma/Laser/Storage/Other/
      Color/Monochrome
   c. Speed
      Refresh/Rewrite Rates
   d. Resolution/Capacity
      Dot Matrix/Vector Inches/Sec.
   e. Rendition
      Color Hues/Luminance/Shading

3. Direct Terminal Support (Software/Firmware/Hardware):
   a. Character/Vector/Circle Drawing Support
   b. Coordinate Expansion/Transformation Support
   c. Color/Shade/Texturing/Tiling/Curved Shading Capabilities
   d. Manufacturers Software Options
   e. User Programmable
   f. External Communications Support (host computer/ peripheral device)
   g. Expandability/Configuration Flexibility
   h. Number of Channels/Resolution per Channel
   i. Special Effects/Fog/Haze/Clouds/Variable Lighting

4. Processor/Host Computer Functions:
   a. Display Format and Output
   b. Coordinate Expansion/Transformation Support
   c. Interactive Response Delays
   d. Image Input/Generation
   e. Image Initiation (Operator Input)
   f. Peripheral Device/Communications Support
   g. Operator Feedback Response/Analysis
   h. Non-display Computational Capability
   i. General Purpose Computers
      (1) Computer Identification (Type/Configuration)
      (2) System Configuration
      (3) Capacities
   j. Special Purpose Computers
   k. Standard CGI Software Options
   l. Custom Software Capabilities

5. System Characteristics/Measures:
   a. Image Rate
   b. Edge Definitions
   c. Cost Performance Measures
   d. Growth Capability vs. Cost vs. Performance and Barriers
   e. Visual Field of View/Resolution

f. Depth of Field/Perspective/Convergence

g. Other visual capabilities/Peripheral cues/Area of Interest displays Helmet mounted/Eye tracking

6. Other Data Elements:

   a. Cost/Performance Parameters

   b. Cost Intensive Functions/Factors

   c. Technological Constraints

   d. Anticipated Capabilities

The following page depicts the format for displaying the collected CGI visual system data in the PMTRADE report. The additional data elements contained above, which are over those shown on the following table, will be appended to the table as discussions.

VENDOR									
MODEL/YEAR									
TYPE									
APPLICATION									
DATA BASE EDGES/LIGHTS									
DISPLAYED EDGES/LIGHTS									
DISPLAY RESOLUTION (ARC-MIN)									
EDGE CROSSINGS PER SCAN LINE									
SCAN RATE									
CONTRAST RATIO									
BRIGHTNESS (FT-LAM)									
FOV PER DISPLAY									
COLOR RANGE									
FACE SHADING									
TEXTURED WATER									
MOVING OBJECTS									
DELIVERY LEAD TIME									
COST RANGE									

APPENDIX C

CGI CONTACT LISTING

This appendix provides PMTRADE with a listing of those academic, Government and industry individuals and/or organizations which can provide products, advice, assistance, data or information concerning all areas of CGI visual technology. The listing is alphabetical and contains organizational names and mailing addresses, individual names and telephone numbers, and, where the information was available, the area of CGI visual system expertise in which the individual or organization can assist. It should be noted that where the area of expertise is listed as "All", that does not mean, in all cases, that the particular individual listed is the expert. Some organizations prefer that all outside contact be made through a single point of contact.

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Advanced Technology Systems 17-01 Pollitt Drive Fair Lawn, NJ 07410	Mr. R. Draudin (201) 794-0200	All ATS COMPUTROL System
American Airlines Flight Academy American Airlines Plaza Fort Worth, TX 76125	Mr. Herbert D. Cooles (817) 267-4172	All
American Institute for Aeronautics and Astronautics (AIAA)	Mr. Kenneth Dydo Rockwell International P.O. Box 92098 Los Angeles, CA 90009 (213) 647-6881	1981 AIAA Simulation Technology Conference information (June 1981-Long Beach, CA)
American Institute for Aeronautics and Astronautics (AIAA)	Mr. Victor Faconti Singer Company Link Division Binghamton, NY 13902 (607) 772-3011	AIAA Working Group on Training and Simulation Facilities
American Institute for Aeronautics and Astronautics (AIAA)	Mr. James Copeland National Aeronautics & Space Administration Langley Research Center Mail Stop 125-B Hampton, VA 23365 (804) 827-2970	AIAA Working Group on Simulator Facilities
American Institute for Aeronautics and Astronautics (AIAA)	Mr. Walter W. Watson Manager, Dept. 3841/64 Northrop Corporation 3901 W. Broadway Hawthrone, CA 90250 (213) 970-4595	Information on AIAA Ground Test and Simulation Committee AIAA Simulation Technology Conferences Northrop Simulation efforts.
Association for Computing Machinery (ACM)	Dr. Douglas Green Texas A&M Electrical Engineering Department College Station, TX 77843 (713) 845-7441	Information on ACM SIGGRAPH "81" Conference

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Association for Computing Machinery (ACM)	Dr. A. Lucido Intercomp 1201 Dairy Ashford Houston, TX 77079 (713) 497-8400	Information on: ACM SIGGRAPH "81" Conference Intercomp Graphics products
Association for Computing Machinery Order Department P.O. Box 64145 Baltimore, MD 21264		Information on copies of SIGGRAPH Conference proceedings
Boeing Aerospace Co. P.O. Box 3999 Mail Stop 82-87 Seattle, WA 98124	Dr. Richard A. Barker (206) 773-1384	Perception/Cuing
Boeing Aerospace Co. P.O. Box 3999 Mail Stop 82-87 Seattle, WA 98124	Mr. Richard Farrel (206) 773-1384	Perception/Cuing Visual Systems Design
Boeing Aerospace Co. P.O. Box 3999 Mail Stop 82-87 Seattle, WA 98124	Mr. Michael L. Cyrus (206) 773-1885	Current Technology and Techniques Boeing R&D efforts High edge capacity systems
Boeing Computer Services Kent Space Center 20403 68th Ave., S. Kent, WA 90031	Mr. Loren Carpenter (206) 241-3946	Fractal Texturing Methodology
Boeing Military Airplane Company 3801 S. Oliver Mail Stop K75-78 Wichita, KS 68210	Mr. Robert J. Rue (316) 686-1091	Visual Requirements Ames Advanced Visual study efforts
Defense Mapping Agency Attention: STT U.S. Naval Observatory, Building 56 Washington, DC 20305	LTC Ralph M. Danielson (202) 254-4457	DMA Digital Data Bases Universal Data Base Technology efforts

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Evans and Sutherland Corporation 580 Arapeen Drive Salt Lake City, UT 84108	Mr. R. Rougelot (801) 582-5847	All E&S Visual Systems CT-4 CT-5 SP-1 SP-2
General Electric Co. Simulation & Control Systems Division P.O. Box 2500 Daytona Beach, FL 32015	Mr. Jeffrey Neal (904) 258-2286	All GE COMPU-SCENE systems
Gould, Inc. Simulation Systems Division 50 Marcus Drive Melville, NY 11747	Mr. William Shaver (516) 454-6300	All GVS-1 System
Grumman Aerospace Corporation Mail Stop A08-35 Bethpage, NY 11714	Dr. Geoffrey Gardner (516) 575-6166	All Non-edge based technology efforts in support of USAF contracts
IKONAS Graphics Systems 403 Glenwood Ave. Raleigh, NC 27603	Mr. N. England (919) 833-5401	IKONAS 3-D Interactive color graphic systems solid object generation techniques Shading techniques
Krupp Atlas Electronics 2800 Bremen 44 West Germany	Mr. Herwing Meyerhoff Mr. Karl Heinz Rybak 011-49-421-45-831	Submarine periscope simulators Ship bridge simulators
LeMateriel Telephonique (LMT) Simulateurs & Electronics System Division 3 Avenue Albert Einstein Zone Industrielle 78190 Trappes, France	Mr. Jean Baradot 011-33-3-050-61-01	Tank driver and tank fire simulators

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Logicon, Inc Tactical & Training Systems Division 4010 Sorrento Valley Boulevard P.O. Box 80158 San Diego, CA 92138	Mr. Robert K. Gullen (714) 455-1330	All Current technology USAF-FDL CIG applications study
Lufthansa German Airlines 6000 Frankfurt/Main Airport West Germany	Mr. Deiter Hass 011-49-611-696-2341	Lufthansa CIG simulator systems European technology
Messerschmitt Balkow Blohm (MBB) Gmbh U.A. Division Postfoch 80 11 49 8000 Munchen 80 West Germany	Mr. Peter Guldenpfennig 011-49-89-6000-3811	All PANAVIA TORNADO simulator
McDonnell-Douglas Electronics Co. Simulation Systems Box 426 St. Charles, MO 63301	Mr. Ronald L. Williams (314) 925-4455	All VITAL Systems
National Aeronautics & Space Administration Simulation Sciences Division Ames Research Ctr. Moffett Field, CA 94035	Mr. Anthony M. Cook (415) 965-5162	All NASA Ames Singer Link system
National Aeronautics and Space Administration Johnson Space Center Mail Stop FE4 Houston, TX 77058	Mr. Wayne Williams (713) 483-2531	JSC Singer-Link Space Shuttle simulator

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
National Aeronautics and Space Administration Johnson Space Center Mail Stop FE4 Houston, TX 77058	Mr. G. Weingardner (713) 483-6101	Simulator development Transport delays
National Aeronautics and Space Administration Langley Research Center Mail Stop 125-B Hampton, VA 23365	Mr. Roland Bowles (804) 827-3304	Wide-Angle Visual Electronics System (WAVES) project
National Aeronautics and Space Administration Langley Research Center Mail Stop 125-B Hampton, VA 23365	Mr. James Copeland (804) 827-2970	Langley Simulator Hardware Langley Applications Software
National Aeronautics and Space Administration Langley Research Center Mail Stop 494 Hampton, VA 23365	Mr. J. Hatfield (804) 827-3291	Real-time cockpit display Electronic Attitude Display Indicators (EADI) Electronic Horizontal Situation Indicators (EHSI) IKONAS Graphics system efforts
Naval Training Equipment Center Experimental Computer Simulation Laboratory (Code N-74) Orlando, FL 32813	Mr. J. Booker (305) 646-4437	Current technology and techniques Interactive Data Base generation LLL Daytime efforts NTEC 8741 project

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Naval Training Equipment Center Experimental Computer Simulation Laboratory (Code N-74) Orlando, FL 32813	Mr. J. Jancaitis (305) 646-4437	Automated data base techniques Universal data base language efforts DMA data base user efforts NTEC 8742 project
Naval Training Equipment Center Experimental Computer Simulation Laboratory (Code N-74) Orlando, FL 32813	Dr. C. Lindahl (305) 646-4491	All N-74 efforts
Naval Training Equipment Center Engineering Concepts (Code N-214) Orlando, FL 32813	Mr. R. Gordon Palmer (305) 646-5354	All Visual system design, development and acquisition Current technology
Naval Training Equipment Center Visual Technology Research Simulator (VTRS) (Code N-732) Orlando, FL 32813	Mr. W. Chambers (305) 277-5354	VTRS
Naval Training Equipment Center Visual Technology Research Simulator (Code N-732) Orlando, FL 32813	Dr. Stanley Collyer (305) 646-5130	Perception/Cuing Scene Content
Ohio State University Research Center Computer Graphics Research Group 1314 Kinnear Road Columbus, OH 43212	Dr. C. Csuri (614) 422-3416	3-D Color Graphics High density scenes Procedure models Terrain Modeling

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27606	Mr. Raphael Montoya (919) 541-6807	Real-time cockpit displays IKONAS Graphics systems NASA Langley contractor
Redifon Simulation, Incorporated 2201 Arlington Downs Road Arlington, TX 76011	Mr. Roy Molynex (817) 469-8411	All E&S/Redifon visual systems
Mr. John B. Sinacori Engineering Consultant P.O. Box 1043 Hollister, CA 95023	Mr. John B. Sinacori (408) 637-3409	Flight simulators Perception/Cuing Scene content and richness Consulting
Singer Company Link Division Advanced Products Division 1077 E. Arques Ave. Sunnyvale, CA 94086	Mr. James J. O'Connell (408) 732-3800	All S-L F-111, B-52 and USAF Project 2360 systems
Technology Services Corporation 2950 31st Street Santa Monica, CA 90405	Dr. A. T. Zavodny (312) 450-9755	Image data base formats Scene synthesis programs Non real-time large-edge capacity scenes
University of Southern California Information Sciences Institute 4676 Admiralty Way Marina Del Rey, CA 92091	Dr. Danny Cohen (213) 822-1511, Ext. 105	All CGI Consulting NTEC Report 77-C-0154-1 "Summary of the CIG Survey"
University of Texas at Dallas Department of Mathematics Mail Station J04.2 P.O. Box 688 Richardson, TX 75080	Mr. Bruce Maylar (214) 690-2170	Hidden surface algorithm methodologies

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
U.S. Air Force Aero-medical Research Laboratory Attention: AFAMRL/HEA Wright-Patterson AFB, OH 45433	Dr. Kenneth Boff (513) 255-4820	Sensory and Perception Requirements studies USAF Integrated Cuing Requirements study
U.S. Air Force Aero-nautical Systems Div. Attention: ASD/YWE Wright-Patterson AFB, OH 45433	Mr. James Basinger (513) 255-4307	All USAF SIMSPO efforts Display/Image Generation working group for the visual SUBTAG
U.S. Air Force Aero-nautical Systems Div. Attention: ASD/YWE Wright-Patterson AFB, OH 45433	Mr. Arthur Doty (513) 255-4591	All USAF SIMSPO efforts
U.S. Air Force Wright Aeronautical Laboratories Attention: ASWAL/FIGD Bldg. 145, Area B Wright-Patterson AFB, OH 45433	Mr. James Eicher (513) 255-4690	All USAF-FSL Report on CIG Applications
U.S. Air Force Human Resources Laboratory Attention: AFHRL/OTFS Williams AFB, AZ 85224	Mr. E. Monroe (602) 988-2611	All Perception/Cuing Display/Image Generation Working Group for the Visual SUBTAG
U.S. Air Force Rome Air Development Center Attention: IRRP Griffis AFB, NY 13441	Mr. V. Nardozza (315) 330-7090	USAF Advanced Image Simultation and Image Synthesis programs
U.S. Air Force Tactical Air Warfare Center Attention: TAWC/OA Eglin AFB, FL 32542	Mr. Jerry Bunting (904) 882-4648	USAF "Simulator Comparative Evaluation" report

Organization/Agency Mailing Address	Contact Individual(s) Telephone	CGI Area of Expertise
U.S. Army Aero-mechanical Lab. Ames Research Center Attention: Mail Stop 215-1 Moffett Field, CA 94035	Col. A. Deel (415) 965-5891	Rotor Craft Wide Angle Visual/Inter-changeable Cab efforts NOE Simulation
Vought Corporation P.O. Box 225907 Dallas, TX 75265	Mr. C. E. Mattlage (214) 266-2546	All Vought FLIR Sensor Simulation efforts

APPENDIX D

CGI BASIC CONCEPTS

The following CGI introductory information was extracted from a Logicon, Incorporated report prepared for the U.S. Air Force Flight Dynamics Laboratory, entitled "CIG Applications Study". The intent is to provide, to those readers who may require it, information on the basic concepts involved in computer image generation.

D-1. CIG FAMILIARIZATION

D-2. CIG Concept

Computer Image Generation (CIG) or Computer Generated Image (CGI) or Digital Image Generation (DIG) is the technology (art) of portraying a visual scene using computers, special purpose hardware, and a digitally stored visual data base which has been previously built for the purpose.

The following sections will be used to bring the neophyte CIG user up to a level of understanding that will allow him/her to comprehend the impact of some of the figures and limits discussed later. The advanced reader may skip this appendix and return to Section IV.

The computer-generated picture is produced very much like that of a newspaper or magazine picture. If either one of these pictures were magnified, it would become apparent that the picture was composed of many small dots. In the case of colored pictures the dots would be colored (usually RED, BLUE, GREEN). This technique using dots to produce a picture may be thought of as a quantitized representation of the visual scene. The point being made here is that a quantitized representation of a scene can look almost as real as the actual scene itself. The number of dots, the size of the dots and the distance from the picture all contribute to its fidelity.

Now that we agree that a picture can be made of many small dots, the next step is to provide motion to the scene created, either by the motion of objects in the scene and/or the motion of the viewer. This is done by creating a new scene at a given rate (the rate may vary but 30 Hertz is the standard U.S. TV update rate, known as the frame rate). If we can put a group of dots on a screen to form a picture and then create a new picture with

these dots within 33.3 milliseconds (30 Hertz), we can produce what appears to be a moving picture. If we display alternate halves of the frame 60 times a second (60 Hertz), or every 16.7 milliseconds, we can eliminate flicker. Each half frame is known as a field.

The following discussion will show how a scene is transformed from its real world representation to its elementary parts (dots). At this time, let's make the conversion to the standard graphics terminology by calling the "dots" picture elements or pixels.

The "world" is first transformed into objects that can be defined by mathematical equations and characteristics (i.e., tree = cylinder, brown + cone, green). See Figure D-1.

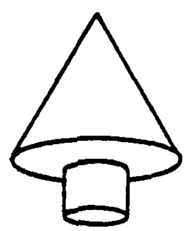

Figure D-1. Representing a Tree

Now that the world has been defined, the viewer is allowed to proceed through it. The simulation system rather than the CIG system controls the world and where moving models are placed. Therefore, the simulation system provides position and change rate information to the CIG system on a continuing basis (this is known as the simulation update rate). The CIG system uses the position and altitude and attitude information to determine the possible visual sphere (i.e., east end of L.A. International looking west, Figure D-2A, D-2B, D-2C). The next step is to reduce the amount of visual data to only that visible through the windows of

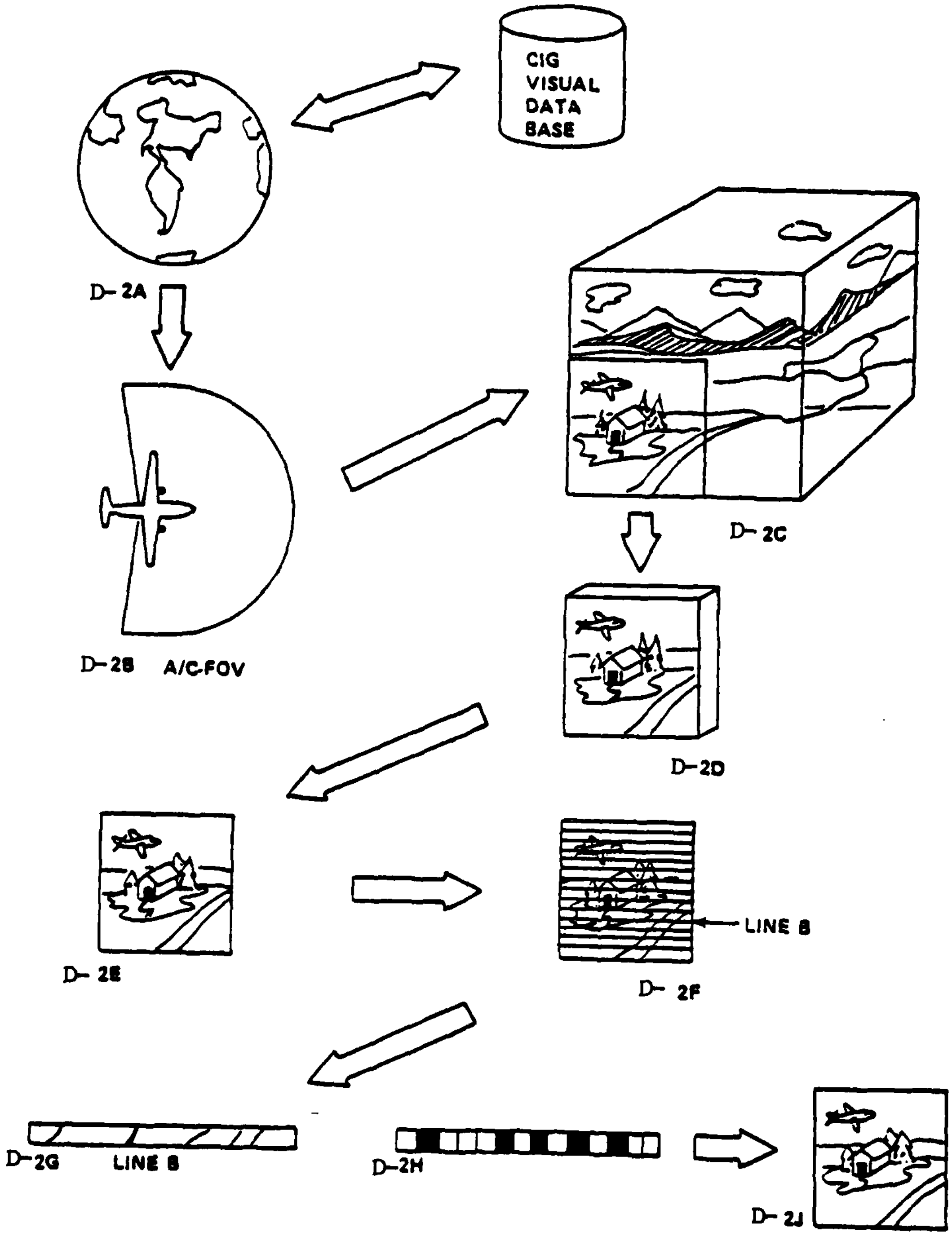

Figure D-2. CIG Scene Creation

the simulated vehicle, D-2C to D-2D. Once this has been done, the three-dimensional scene must be put in perspective and converted to a two-dimensional scene for presentation, Figure D-2D to D-2E. We know that the picture is made up of a matrix of dots or pixels; therefore, our next step is to take the 2D picture and subdivide it into a line of picture elements (pixels/dots), Figure D-2F. Now we calculate each picture element of that line to determine its attributes (shade or color), Figure D-2G, D-2H. Now begins the construction of the actual picture. The picture element data is fed to the display device and the new picture is constructed, Figure D-2J. All of the preceding calculations are done within 33 milliseconds (up to 1,000,000 picture elements).

D-3. CIG Basic Approach

The following discussion is a description of the basic functions of today's typical CIG system. It is necessary to understand these basic functions to appreciate the problems involved in presenting an acceptable computer image.

Many of the anomalies unique to a raster-type presentation are consequences of the way the picture is constructed and therefore an understanding of this construction is important.

Various systems use slightly different approaches, but basically they are all very similar to the one described.

a. Data Base Creation. See Figure D-3.
Normally in a motion picture production the scenes are recorded on film and then developed to enable presentation. In a CIG system the act of photographing is done by an artist/engineer (in whatever order you want). He first analyzes many pictures, drawings, and in some cases the actual scene, and then he constructs the model. The model must be as realistic as possible but must be drawn

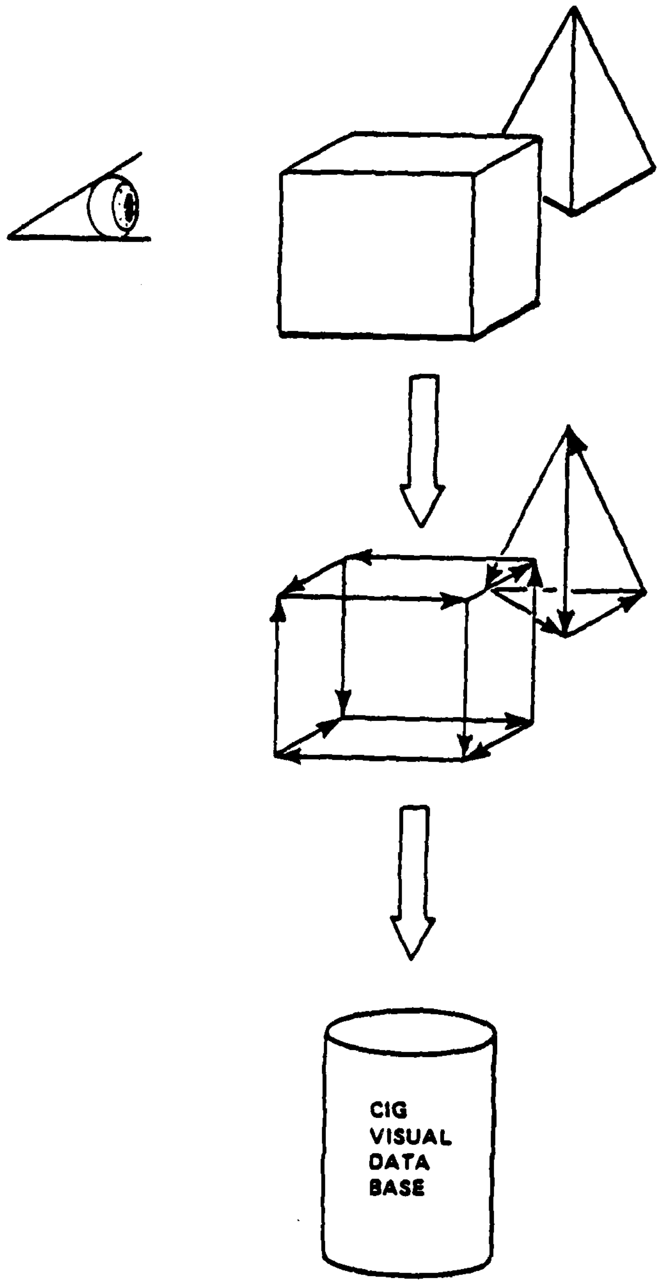

Figure D-3. CIG Data Base Creation

using the most efficient CIG methods (i.e., as few edges as possible). Once he has finished his drawing, he transfers the model into the CIG data base. This is similar to the photographer taking the pictures and is done by converting the model into a number of polygons. These polygons will have attributes such as color, position, relationship to other polygons, etc. All this information is converted into a digital representation that is stored in the CIG data base. Some of the problems encountered in this area are:

1. Possible size of the data base
2. Ease of modeling the scene in the CIG system
3. Commonality between various CIG data bases (Simulator to Simulator), Sensor and CIG.

The CIG data base manager serves as the film processor by taking modeling information and storing it into the data base (film).

b. Determining Orientation

At this point the recorded scenes are stored in the data base. They now are in a digitized usable format for the real-time CIG system to use. The real-time processing can be likended to the projection of a movie film.

Once the gaming area has been recorded, the problem is to provide for the CIG viewer. He must be able to proceed through the CIG visual environment in any way he wishes. To do this the real-time CIG system must be able to cons:ruct scenes from any viewing reference and lighting conditions. Allowing the viewer to interact with the visual scene is where the CIG system departs somewhat from the normal movie. The following discussion will explain how the real-time presentation is accomplished.

The first thing that has to be done is to establish where the viewer is in this expansive gaming area. See Figure D-4. Since the gaming area may be as large as 600 by 600 nautical miles, a sphere of possible visual data must be established which is a subset of the total gaming area. The size of the visual sphere is controlled by the field of view provided to the viewer. This sphere of possible visual data is also referred to as the "Active Data Base". This data resides in the CIG memory for fast and easy access.

The active data base is of interest because it represents the available scenery that can be shown at any one instant. If the active data base is exceeded (i.e., the vehicle moves so fast that the area of visible scenery has moved out of the active data base) then the scene will obviously deteriorate.

The next bit of information positions the projector in our movie analysis. This information is the position attitude and change rates provided by the simulation program. This information is used to position the spot where the eye is viewing the outside world. The active data base information is rotated into the viewer's coordinate system to allow for follow-on processing.

c. Determining What Is Visible

The problem now is to calculate the visual information that is actually visible to the viewer. See Figure D-5. For this example, we will assume that the CIG projection system is a mosaicked CRT presentation. (That is, the field of view is made up of multiple CRTs butted together to provide a total scene.) The continuing discussion will now concentrate on the CIG system's presentation of

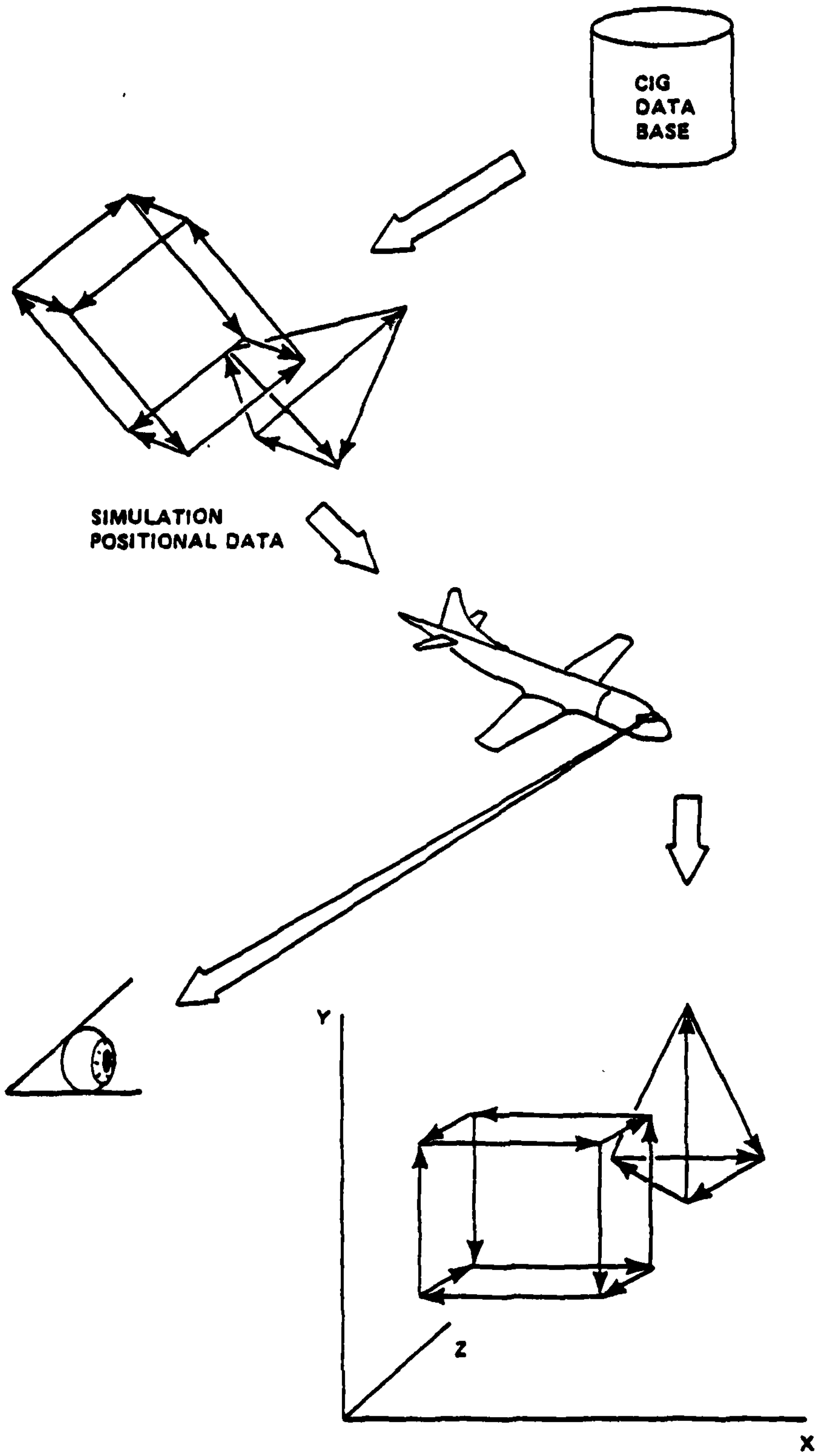

Figure D-4. Orientation of Presentation

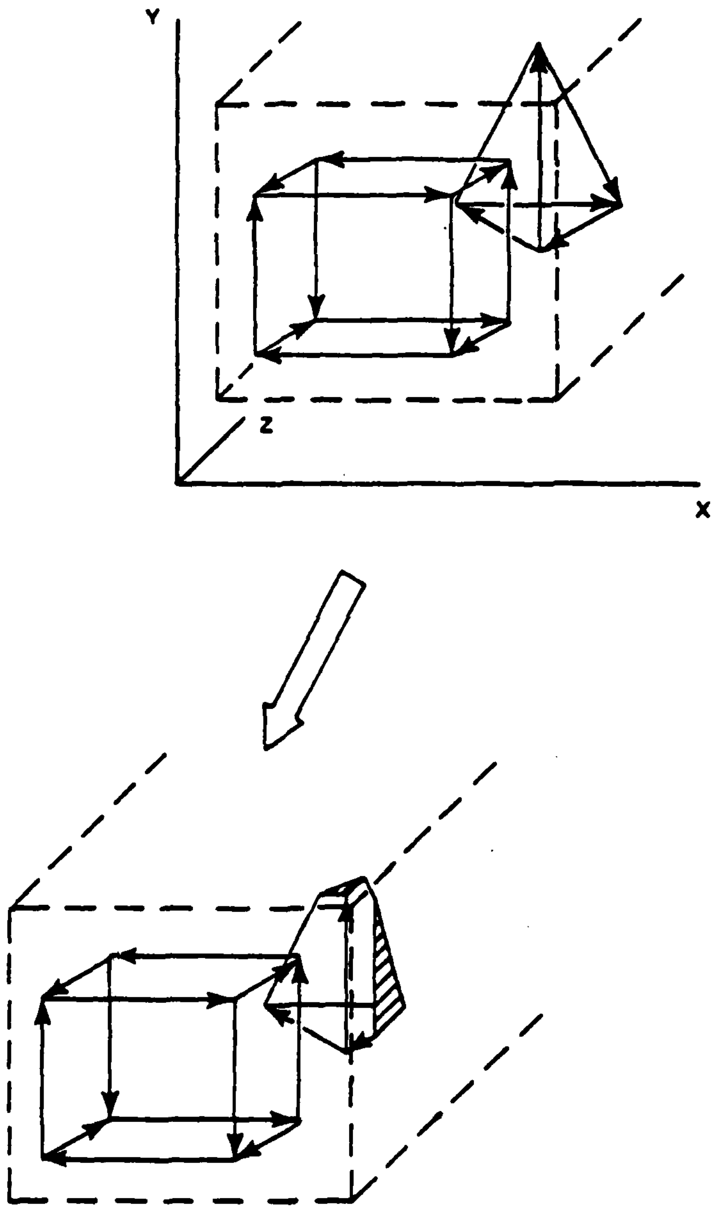

Figure D-5. Determining What Is Visible

a scene on one of these CRTs. The same technique is used for the remaining CRTs. The example here is directed at a mosaicked system but could be a view from other windows or instructor viewpoints, etc.

An imaginary window the size of the CRT is placed between the viewer and the outside world. Then the scenery, including moving models, is projected onto the imaginary window plane. The visual information that is not required is clipped away so that the remaining data left to process is that area that is formed by the CRT WINDOW and its Z extension away from the viewer. The objects are put into perspective size, dependent upon their distance from the viewer. At this point, the level of detail of the model has been determined. (The level of detail an object has is dependent upon its range from the viewer. The idea is to conserve on the edge calculation time in cases where the detail would be so small that it could not be distinguished anyway, i.e., as the object moves closer to the viewer, more and more detail of the object is seen.)

At this stage the objects within the window of the scene have been defined by:

1. Levels of visibility
2. Their priority (i.e., who is behind whom)
3. The object's proper level of detail

d. Creation of the Two-Dimensional Scene. See Figure D-6. The next step is the creation of a two-dimensional scene. This means that all of the objects that have faces that cannot be seen from the viewpoint will be dropped from consideration. What is left is the list of possible visible object faces, i.e., those facing the viewer are only potentially visible because other faces, which

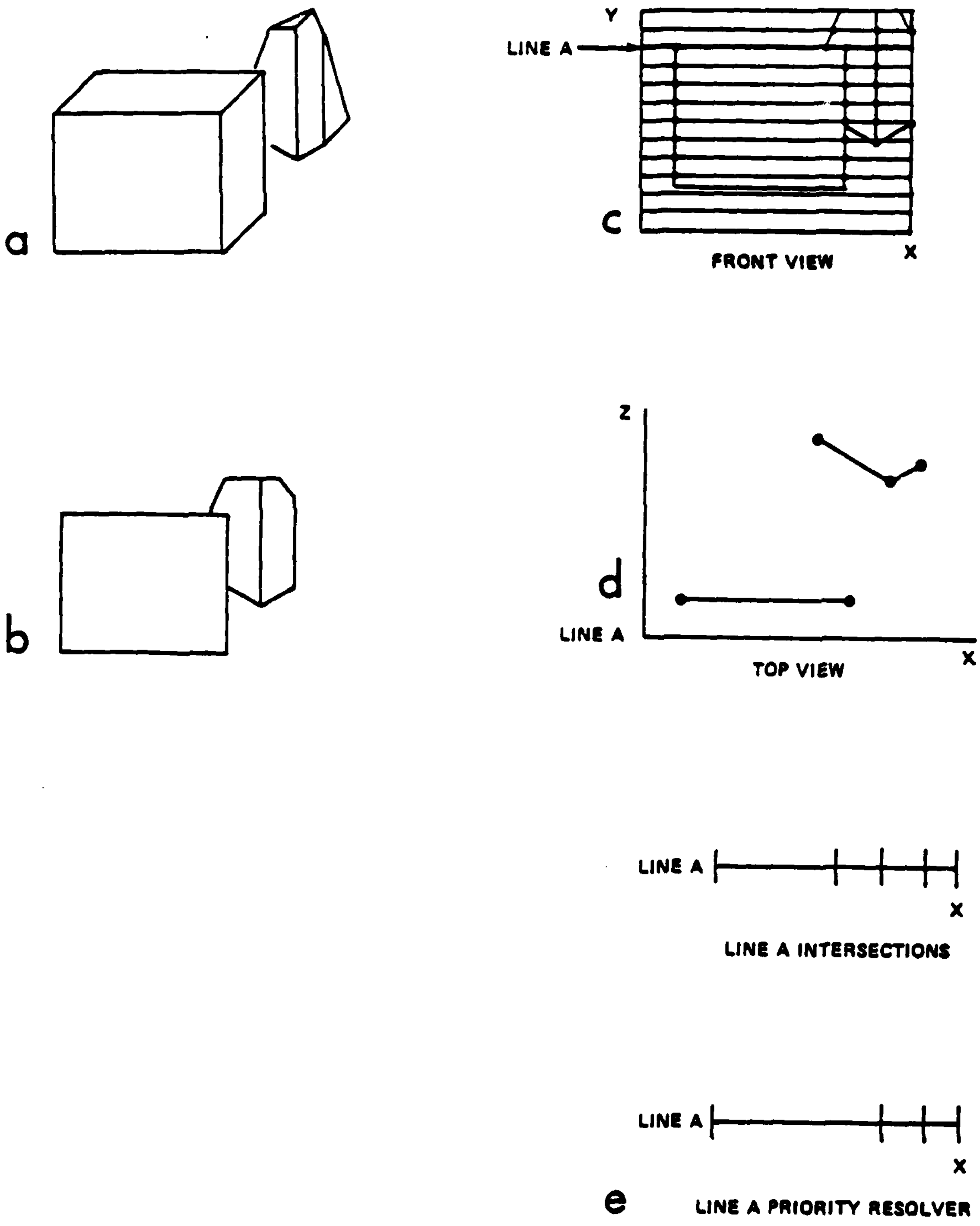

Figure D-6. Creation of the Two-Dimensional Scene

would occlude or occult them, may be between them and the viewer.

Now the remaining visual volume will be dissected by passing a number of horizontal (could be vertical) planes through the scene. This will produce the raster scan lines of the scene. The number of the cuts or lines is dependent upon the screen resolution which represents the CIG picture. Currently, that range approaches 1024 scan lines. Now that we have the scene dissected into many lines, the next process determines the composition of the scan line. Figure 6b shows what the screen looks like from a point in front of the screen. In Figure 6d, a slice of the dissected scene is rotated such that the view is from the top or X,Z plane. As you can see, some of the faces fall behind others in this figure. The priority processing determines which of these faces (which are now lines because we are only looking at a slice through the Y-axis) are in front of the others. This is done using a subdivision algorithm which looks for the start points and stop points of line segments. These start and stop points are generated when the edge of a face crosses a scan line. The number of priority calculations done on a scan line becomes important when the "edge-crossings-per-scan-line" figure is discussed. The magnitude of these calculations is related to the number of edges that cross the scan line. The algorithm tries to reduce the lines encountered in the X,Z plane to one continuous scan line along the X-axis eliminating the occulted line segments.

When this processing has been accomplished, a scan line is complete with the highest priority segments represented

across the scan line as in Figure D-6e. The next processing phase will deal with the subdivision of the scan line into pixels. This processing does the smooth shading of each pixel and applies any texture required.

Now we have broken the picture down to its smallest part and the next process sends these out to the proper display channel for presentation by the display system.

For additional information on the "HOW" of CIG, refer to:

1. Newman & Sproull, 1973
2. Sutherland et al., 1974
3. Bennett, 1975
4. Raike, 1976

APPENDIX E

SYSTEMS CAPABILITIES SUMMARY

This appendix provides the reader with quick reference summary tables describing current and developmental system capabilities. The information in Table E-1 represents current vendor offerings, as described in their responses to the technical survey conducted during this study effort. The descriptions displayed in Table E-2 were obtained from the vendors, published articles or from the developmental agencies. For further explanation or technical descriptions, the reader should refer to Section 4, 5, or to the appropriate vendor's section of the CGI technical reference library supplied with this report. Table E-3 is a brief description of current and proposed Navy flight trainers with visual systems (provided by NTEC).

VENDOR	GE	GE	S-L	S-L	E&S/Redifon	E&S/Redifon	E&S/Redifon	M-D	Gould
MODEL/YEAR	COMPU-SCENE I 1976	COMPU-SCENE II 1979	F-111	B-52	CT-5	SP-1	SP-2	VITAL IV	GVS-1 1981
TYPE	Raster	Raster	Raster	Raster	Raster	Hybrid Calligraphic	Hybrid Calligraphic	Calligraphic	Raster
APPLICATION	D/D/N	D/D/N	D/D/N	D/D/N	D/D/N	N	LLLD/D/N	LLLD/D/N	D/D/N
DATA BASE EDGES/LIGHTS	10,000	40,000	75,000	500,000	Limited only by Disk	448 Edges (3) 350 Surfaces 4800 Lights	1152 Edges (3) 1008 Surfaces 5000 Lights	Combination to 15,000 surfaces or 40,000/400,000 (4)	Limited only by Disk
DISPLAYED EDGES/LIGHTS	2,000/2,000	8,000/8,000	Combination to 8,000	Combination to 12,000	2500 Poly/Sys. 1000 Poly/Ch (2) or 4000 Lights	256 Edges 200 Surfaces 4800 Lights	512 Edges 450 Surfaces 5000 Lights	Combination to 300 surfaces or 800/8,000 (4)	2,000/4,000
DISPLAY RESOLUTION (ARC-MIN)	4	2.2	3	3	7	7.7	7.7	5.4 (5)	9 (5)
EDGE CROSSINGS PER SCAN LINE	256	600	256	512	No Restrictions	128/Channel none/system	256/Channel none/system	-	Not a Limitation
SCAN LINES	525	875	1,000 (Vert. Scan)	875 (horz Scan)	700	600	600	-	-
CONTRAST RATIO	20:1	25:1	10:1	10:1	30:1	15:1	30:1	30:1	Customer Option
BRIGHTNESS (FT-LAM)	6	6	50 (1)	50 (1)	10	3.5	7 Lights 2.5 Surfaces	.01 to 2	Customer Option
FOV PER DISPLAY (HXV)	$40^{\circ} \times 30^{\circ}$	$43^{\circ} \times 32^{\circ}$	$48^{\circ} \times 36^{\circ}$ (Typical)	$48^{\circ} \times 36^{\circ}$ (Typical)	$48^{\circ} \times 36^{\circ}$ (Typical) up to 8 channels	$48^{\circ} \times 36^{\circ}$ up to 8 channels	$48^{\circ} \times 36^{\circ}$ up to 8 channels	$45^{\circ} \times 35^{\circ}$, $48^{\circ} \times 36^{\circ}$ or $60^{\circ} \times 45^{\circ}$	Customer Option
COLOR RANGE	Full	Full	Full	Full	Full	No Blue	Full	No Blue	Full
FACE SHADING	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TEXTURED WATER	Yes (Point Lights)	Yes (Patterns)	Yes	Yes	No	No	No	No	Yes
MOVING OBJECTS (#)	Yes (2)	Yes (8)	Yes (6)	Yes (6)	Yes	Yes (up to 6)	Yes (up to 6)	Yes (3)	Yes
DELIVERY LEAD TIME	18 mo.	30 mo.	20 mo.	24 mo.	18 mo.	9 mo.	12 mo.	9 mo.	16-18 mo.
COST RANGE	\$2.0m - \$4.0m	\$3.0m - \$6.0m	-	-	-	-	-	-	\$200K-500K per channel

Legend:
D/D/N - Day/Dusk/Night
LLLD/D/N - Low Light Level Day/Dusk/Night
N - Night only

NOTES:
(1) Center of Display.
(2) E&S uses polygons to express capacity. Additional channels do not affect capacities.
(3) Larger data bases available with automatic data base management.
(4) Based on an edge to surface ratio of 2.67:1.
(5) Assuming $48^{\circ} \times 36^{\circ}$ FOV.

Table E-1 Summary of Current System Capabilities

	1	2	3	4	5	6	7	7a	7b
VENDOR	ATS (1)	GE (2)	S-L (2)	GE (2)	E&S (3)	Unknown (4)	GE (5)	---	---
MODEL/YEAR	COMPUTROL	C-130	B-52 Prototype	B-52 Prototype	USMC CH-46 (CT-5)	Army/NASA Ames ACAVS	VTRS/1978	VTRS-CTOL(5)	VTRS-VTOL (5)
TYPE	Raster	Raster	Raster	Raster	Raster	-	Raster	-	-
APPLICATION	D/D/N	D/D/N	D/D/N	D/D/N	D/D/N	D/D/N	D/D/N	-	-
DATA BASE EDGES/LIGHTS	Unlimited depending on hardware	Limited by source data (DMA and enhancement)	Limited by source data(DMA and enhancement	Limited by source data(DMA & enhancement)	6667 Edges 2667 per chan. 4000 Lights	-	10,000/4,000	-	-
DISPLAYED EDGES/LIGHTS	10,000/10,000 expandable to 100,000	8,000/4,000	Any combination to 8,000	2,000/2,000	2667/4000	At least 1000 potentially visible edges	2,000/2,000	-	-
DISPLAY RESOLUTION (ARC-MIN)	3	5	3	3	4.5	3	-	8-Background 1 to 5 - Zoom Target	-
EDGE CROSSINGS PER SCAN LINE	Up to 1,000	300/Channel 800/System	512	256	1000	-	256	-	-
SCAN LINES	1029 (CRT)	875	875	875	770	-	1025/825/525	-	-
CONTRAST RATIO	-	25:1	20:1	50:1	25:1	-	-	10:1	10:1
BRIGHTNESS (FT-LAM)	77	10	4	4	4	50	-	4 (monochrome)	1 (color)
FOV PER DISPLAY (HXV)	-	$44^\circ \times 36^\circ$/channel $240^\circ \times 36^\circ$/system	6 FOVs	6 FOVs	Six Channels $48^\circ \times 36^\circ$	$240^\circ \times 180^\circ$	-	$160^\circ \times 80^\circ$ $6^\circ \times 60^\circ$ ZoomTarget	$90^\circ \times 70^\circ$
COLOR RANGE	Full	Full	Full	Full	Full	Full	Full	-	-
FACE SHADING	-	Yes	Yes	Yes	Yes	-	Yes	-	-
TEXTURED WATER	-	Yes	Yes	Yes	No	-	No	-	-
MOVING OBJECTS (#)	Unlimited	Yes	Yes	Yes	Yes	-	Yes (6)	-	-
DELIVERY LEAD TIME	-	Not yet delivered	Not yet delivered	Not yet delivered	Not yet delivered	1982-1984	Located NTEC(N732) DLT was 24 mos.	-	-
COST RANGE	-	- Little Rock AFB	- Castle AFB	- Castle AFB	-	-	4m	-	-

Legend:
D/D/N - Day/Dusk/Night
LLLD/D/N - Low Light Level Day/Dusk/Night
N - Night only

NOTES:
(1) ATS did not respond to the technical survey. The information shown was extracted from a paper published in the proceedings of the 11th NTEC/Industry Conference.
(2) Information provided by the USAF-SIMSPO.
(3) Information provided by N214. The technical characteristics shown are from the CH-46 Specification, therefore, there are some differences from the CT-5 shown in Table E-1.
(4) Information obtained from the NASA Ames SOW and Preliminary report for ACAVS conceptual design study.
(5) Information provided by N732. Items 7a and 7b represent the alternative display systems available on VTRS for meeting the Carrier Take-off and Landing (CTOL) and Vertical Take-off and Landing (VTOL) missions.

Table E-2 Summary of Developmental System Capabilities

NAVY VISUAL SYSTEMS USED FOR TRAINING, AND ASSOCIATED SIMULATORS

(P = PLANNING IN PROGRESS)

WEAPON SYSTEM	SIMULATOR		VISUAL SYSTEM				
	TYPE*	NO.	NO.	IMAGE GENERATOR	FIELD OF VIEW**	DISPLAY	SIMULATED MANEUVER
TA-4J	OFT	9	2	CIG day/night 1000 edges, color raster system.	210°H 60°V	Mosaic of 3 rear-projection flat screens, 3 TV projectors	Carrier & Field Landing Familiarization/cross country. Air-ground weapon
A-4M	OFT WST	PØ	P	P	P	P	Air/Ground
A-6E	OFT	2	2	Calligraphic CIG Night/dusk	48°H 36°V	4-window, 3 channel folded on axis virtual image CRT	Landing, cross country
	NCLT	2	2	Calligraphic CIG Night/dusk	48°H 36°V	2-window, 1 channel folded on axis virtual image CRT	Night and dusk carrier landing
EA-6B	WST	1	1	Calligraphic CIG Night/dusk	120°H 48°V	3-window, 2 channel, folded on axis virtual image CRT display	Night and dusk landing, field and carrier tactical area
A-7E	NCLT	2	2	Calligraphic CIG night	42°H 32°V	1 window on axis virtual image CRT display (refractive optics)	Night carrier landing
	WST	2	2	Video disc stored photographic data, digital scene interpolation	Various, to meet training mission within forward 1/4 sphere and down 30°	Mosaic of 6 rear-projection screens with 4 TV projectors	Air/Ground Weapons cross country field landing

Table E-3

NAVY VISUAL SYSTEMS USED FOR TRAINING, AND ASSOCIATED SIMULATORS

(P = PLANNING IN PROGRESS)

WEAPON SYSTEM	SIMULATOR		VISUAL SYSTEM				
	TYPE*	NO.	NO.	IMAGE GENERATOR	FIELD OF VIEW	DISPLAY	SIMULATED MANEUVER
	LSO Trainer	2	2	Calligraphic CIG night	72°H 36°V	2 edge matched, virtual image displays, refractive optics	A-7 Aircraft approach, carrier, LSO controlled
KC-130	OFT	1	1	TV camera/model board	48°H 36°V	Off-axis concave mirror and projector "(Duoview)"	Takeoff and landing
F-4J	WST	4	1	CIG, night Calligraphic	144°H 32°V	3 window folded on-axis virtual image CRT display	Field and carrier takeoff and landing
F-14A	OFT	4	2	CIG, night/dusk Calligraphic	46°H 32°V	1 window folded on-axis virtual image CRT display	Field takeoff and landing
	WST	2	2	TV camera aircraft and carrier models, "shadowgraph" background	350°H 150°V	Spherical dome screen 5 computer-aimed projectors, one with zoom plus 2 missile projectors	Carrier takeoff and landing, Air/air combat
F-18	OFT	1	1	Calligraphic CIG dusk/night	48°H 36°V	3 window 3 channel folded on axis virtual image CRT	Field and carrier landing, cross country, limited air-surface weapon device
	WTT	2	2	Aircraft models & background, CIG color raster system	360°H 150°V	Spherical dome screen, 4 computer-aimed TV projectors	Air/Air

Table E-3

NAVY VISUAL SYSTEMS USED FOR TRAINING, AND ASSOCIATED SIMULATORS

(P = PLANNING IN PROGRESS)

WEAPON SYSTEM	SIMULATOR		VISUAL SYSTEM				
	TYPE*	NO.	NO.	IMAGE GENERATOR	FIELD OF VIEW**	DISPLAY	SIMULATED MANEUVER
F-4 F-14 F-18	ACMS	1	1	TV camera air-craft model, "shadowgraph" background	350°H 150°V	Spherical dome screen, 4 computer-aimed TV projectors & 1 missile projector	Air/Air
SH-2F	WST	2	2	CIG, night Calligraphic	144°H 32°V	3 window folded, on-axis virtual image CRT display (segmented)	Field, ship and carrier takeoff and ASW tactical operations
CH-46	OFT	3	2	CIG, day/night 6500 edges, color raster system	175°H 50°V + chin window	6 window folded, on-axis virtual image CRT display (segmented)	Field, ship (LPH, LPD) and confined area takeoff and landing
CH-53	OFT	3	P	P	P	P	Field, ship and confined area takeoff and landing
P-3	OFT	5	4	TV camera/ model-board	48°H 36°V	Off axis concave mirror and projector ("Duoview")	Field takeoff and landing
			1	CIG, night/dusk Calligraphic	48°H 36°V	1 window folded on-axis virtual image CRT display	Field takeoff and landing
S-3A	WST	5	5	CIG, night Calligraphic	144°H 32°V	3 window two channel folded on axis virtual image CRT display (segmented)	Field and carrier takeoff and landing

Table E-3

NAVY VISUAL SYSTEMS USED FOR TRAINING, AND ASSOCIATED SIMULATORS

(P = PLANNING IN PROGRESS)

WEAPON SYSTEM	SIMULATOR		VISUAL SYSTEM				
	TYPE*	NO.	NO.	IMAGE GENERATOR	FIELD OF VIEW**	DISPLAY	SIMULATED MANEUVER
TAV-8A	OFT	1	1	P (CIG day/dusk color raster system)	P (200°H) (65°V)	P (virtual image CRT)	Field, ship (LPH, LPD) and confined area takeoff and landing
AV-8B	WST	3	3	P	P	P	Air to ground, visual acquisition of targets

* OFT - Operation Flight Trainer
WST - Weapon System Trainer
PTT - Part Task Trainer
NCLT - Night Carrier Landing Trainer
ACMS - Air Combat Maneuvering Simulator

** H is horizontal field of view (degrees)
V is vertical field of view (degrees)

Ø P is Planning in Progress

Table E-3

APPENDIX F

BIBLIOGRAPHY OF SELECTED CIG REFERENCE MATERIAL

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